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Sources of information should be specifically acknowledged.

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Copies of detailed instructions can be had from the Secretary, Imperial Council of Agricultural Research, New Delhi.

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VOL. XII, PART IV

(August 1942)

The Editorial Committee of the Imperial Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal

THE DESCRIPTION OF CROP-PLANT CHARACTERS AND THEIR RANGES OF VARIATION

BY

G. N. RANGASWAMI AYYANGAR, F.N.I., I.A.S.

AND

MEMBERS OF THE SUB-COMMITTEE

WITH A FOREWORD

BY

W. BURNS, C.I.E., D.Sc.

FOREWORD

THE Imperial Council of Agricultural Research has previously published descriptions of crop-plant characters and their ranges of variation for (1) Indian cotton varieties, (2) Indian rice varieties and (3) Indian wheat varieties. The present paper now describes crop-plant characters and their ranges of variation for another important Indian crop, viz. sorghum, known throughout the larger part of India as *jowar*.

As in the case of the previous crops, the present paper is an attempt to prepare schedules to standardize the description of the crop concerned. It is not to be regarded as an attempt at taxonomic classification. It is an effort to provide agricultural botanists with a standardized method of description so that there may be real comparison between types of the same crop-plant from any Indian source.

As in the case of the previous crops, the work has been carried out by a special sub-committee of which the president was Rao Bahadur G. N. Rangaswami Ayyangar, F.N.I., I. A. S., Millet Specialist to the Government of Madras. The members of the sub-committee were Dr G. S. Bhatia, M.Sc., Ph.D., F.L.S., F.R.M.S., Second Economic Botanist, Central Provinces, Nagpur, Professor L. S. S. Kumar, M.Sc., A.R.C.S., D.I.C., Economic Botanist to the Government of Bombay, Dr T. S. Sabnis, B.A. (Hons.), D.Sc., I.A.S., Economic Botanist to the Government of United Provinces. The drawings and photographs were prepared under the supervision of Rao Bahadur Rangaswami Ayyangar at the Agricultural Research Institute, Coimbatore, by the artists' section. Mr Ayyangar was assisted in the preparation of the note that formed the basis of this publication by his assistant, Mr M. A. Sankara Ayyar, B. A., B. Sc. Ag.

The really important thing is that these schedules, when prepared, shall be used and it is hoped that as a beginning agricultural botanists in all provinces and States in India will describe at least their most well-known varieties by this method, so that a publication comprising these might be prepared at an early date.

W. BURNS

Agricultural Commissioner
with the Government of India

6 January 1942

IV. THE VARIABILITY OF INDIAN SORGHUM (*JOWAR*)

(Received for publication on 22 December 1941)

(With Plates XIX-XXII)

Classification

SORGHUM (*jowar*) is an ancient crop in India as well as in Africa. A number of varieties are grown in both the countries. Though a certain amount of affinity exists between the Egyptian varieties and the Indian varieties grown in the Deccan area, most of the African varieties differ from the Indian varieties. The classification of the numerous varieties has been attempted from very early times by various systematists, but none of these is comprehensive. It is needless to state that all systems of classification especially of varieties in cultivated crops, are assailable from some point of view or other. Nevertheless, the recent classification of the cultivated sorghums by Snowden [1936], at Kew, being the latest and fullest, may be followed for describing the varieties and determining their botanical groups.

Material to be described

For the sake of uniformity, the general trend of the description is that followed in describing rice. As in rice and wheat, the material to be described is of two kinds: one group consisting of strains selected or evolved by the several agricultural research stations which are being grown as departmental improved varieties and the other, of varieties and types collected from various parts of the province or isolated from such varieties and crosses with them. The former may be few, but the latter are numerous. While the description of strains should be as elaborate and as detailed as possible the description of the types in the varietal collections will have to be simpler and should be considered mainly from the morphological and genetical point of view. Even in this it should be enough to confine the descriptions to important varieties or groups of varieties recognized both by cultivators and in trade in the different provinces.

Exotic types and types from other provinces should be left out except such of those as have been found economically useful. When describing types from other provinces or experiment stations, the original number and name of the type should be retained.

Characters to be described

The characters to be described are of two kinds—qualitative and quantitative. The first one is but little influenced by environment. The colour characters come under this category. To facilitate the description of qualitative characters special notes (Appendix I) and coloured plates have been prepared. For uniformity in the naming of the parts, a sketch of a sorghum plant with the parts named has been included (Plate XIX).

The data on more variable quantitative characters like yield are better collected from a properly laid replicated trial. For varieties and types which are not usually grown in replicated plots, the average of a number of seasons in which they are grown in progeny rows may be given with their range of variation.

PARTS OF A SORGHUM PLANT

1. Roots ; 2. Node ; 3. Leaf sheath ; 4. Leaf midrib ; 5. Internode ; 6. Nodal band ; 7. Ligule ; 8. Leaf junction ; 9. Panicle ; 10. Peduncle ; 11. Awn ; 12. Pedicelled spikelet ; 13. Sessile spikelet ; 14. i. Lower glume, ii. Upper glume, iii. Lower lemma, iv. Upper lemma ; 15. Palea ; 16. Stigmas ; 17. Styles ; 18. Anthers ; 19. Lodicules ; 20. Grain

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PIGMENTATION IN ROOTS, LEAF SHEATH AND GLUME

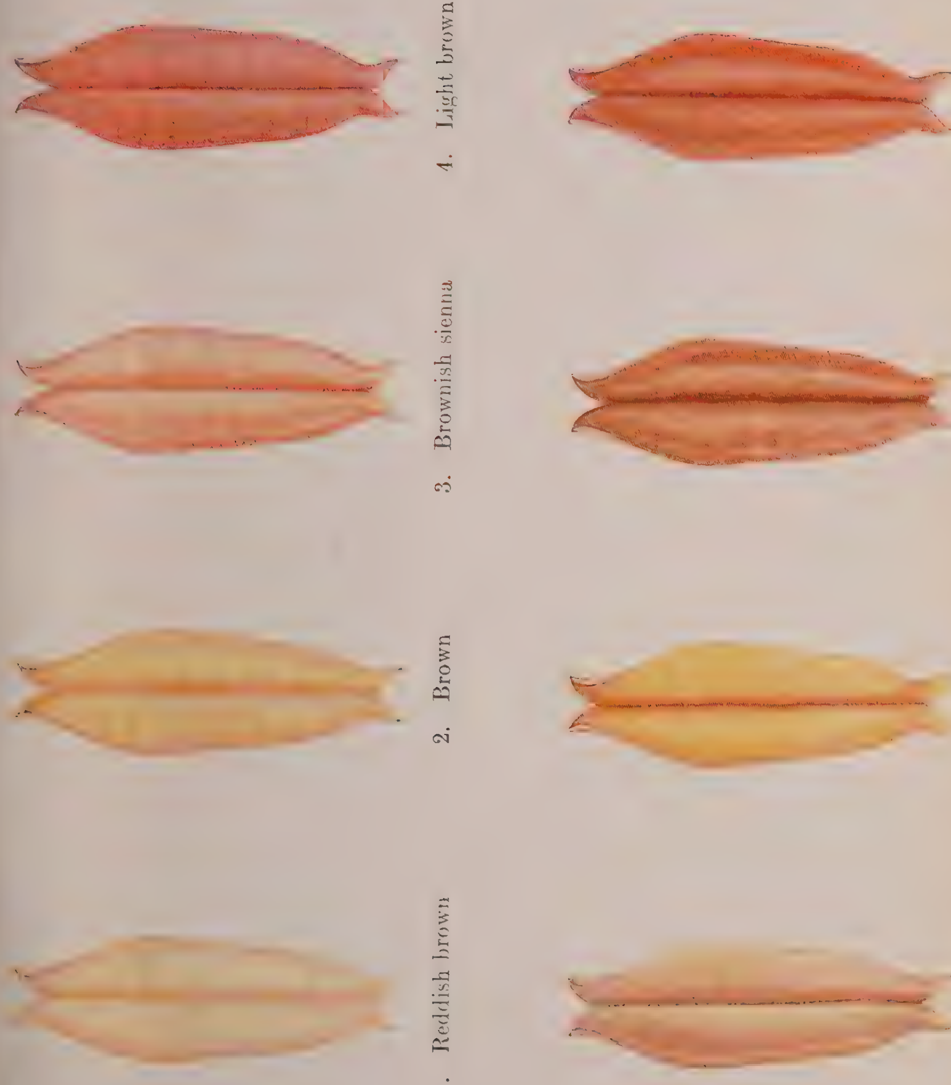
1. Reddish purple   2. Blackish purple   3. Brown

GENERAL SCHEDULE PROPOSED FOR SORGHUM

Experiment Station . . .	Name and place
Variety or type . . .	Number, name (or names), and place of origin. Mention whether simple selection or isolated from cross, and if the latter the parents involved. In the case of mutants also the parent should be mentioned. Botanical group (according to Snowden's classification)
Season of crop . . .	The time of sowing and harvest may be stated, as March to June, July to December, etc. This varies for the same variety in different parts of a district. Sometimes the same variety may be grown in different seasons in the same area. In such a case the different seasons may be mentioned
Nature of crop . . .	(*i*) Rain-fed or irrigated. The system prevailing in the place of origin of the variety may be mentioned separately if it differs from the practice of the Experiment Station (*ii*) For grain or fodder or for both (*iii*) Whether grown pure or mixed with other crops
Habit :	
Seedling	Erect or spreading
Adult	Single stalked or tillering; if tillering, number of tillers which bear good heads
	Morphological characters
Seedling colour (about a month old) Pigmentation . .	Green or bluish green The presence or absence of pigment (colour) in the following parts may be recorded
Root (seedling) . . .	Reddish purple, blackish purple, or brown (Plate XX)
Coleoptile or primary sheath .	Purple (of grades) or green
Leaf-sheath . . .	Reddish purple, blackish purple or brown (Plate XX)
Leaf-axil	Purple (of grades) or green
Internode	Purple or green
Nodal band . . .	Purple, reticulated purple or green
Leaf junction . . .	Purple or green
Leaf-sheath margin . .	Purple or green
Glume tips	Purple or green
Glume (mature) . . .	Reddish purple, blackish purple or brown (straw) (Plate XX)

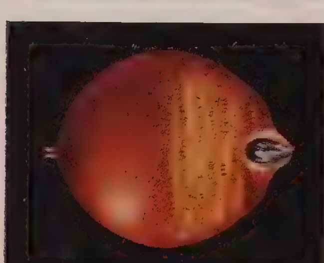
(Pigmentation in any other part may be mentioned)

Hairiness :	
Node	Hairy or glabrous
Leaf junction . . .	Hairy or glabrous
Glume	Densily or sparsely hairy or glabro (fringe hairy)
(Hairiness in any other part may be mentioned)	
Bloom	Heavy or sparse
Nature of stem . . .	Juicy or pithy (at maturity) The cut ends of juicy stems will greenish and those of pithy whit The midrib of leaf in juicy stem w be dull green in colour and in pitl stem, white Sweet or insipid Good for fodder or not
Leaf blade	Colour—green (dark, ordinary or light)
Leaf midrib	White, dull green or yellow
Panicle (earhead) . . .	Emergence Compactness Shape—lanceolate, ovate, elliptic, oblon globose, obovate, or intermediate shap Peduncle—long or short ; straight, twist or recurved
Sessile spikelets :	
Glume size	Short or long ; broad or narrow
Glume shape . . .	Ovate, elliptic, oblong, obovate, or inte mediate shapes
Glume texture . . .	Coriaceous or papery
Glume nerves . . .	Short or long
Glume wrinkling . . .	Wrinkled or not wrinkled, both glumes lower glume only
Glume gaping . . .	Gaping (as in *S. Roxburghii*, where t glumes open out at maturity) or n gaping (clipping the grains)
Awned or awnless . . .	If awned, length of awn
Stigma feathers (fresh) . .	Yellow, light yellow or hyaline
Anther (fresh)	Yellow or light yellow
Anther (dry)	Reddish brown, brown, brownish sienn light brown, red, light red, sienna light sienna (Plate XXI)
Grain :	
Exposure	Well exposed, partly exposed or almo enclosed in the glumes
Size	Bold, medium or small
Shape	Ovate, elliptic, orbiculate, obovate or i termediate shapes

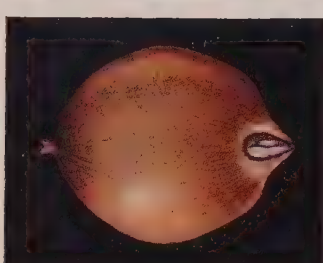


1. Reddish brown
2. Brown
3. Brownish sienna
4. Light brown
5. Red
6. Light red
7. Sienna
8. Light sienna

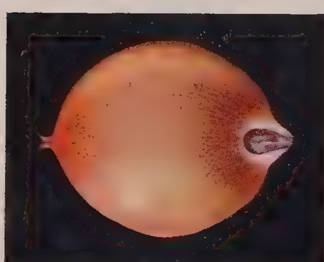
GRAIN COLOURS



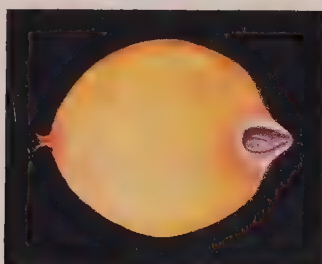
1. Reddish brown



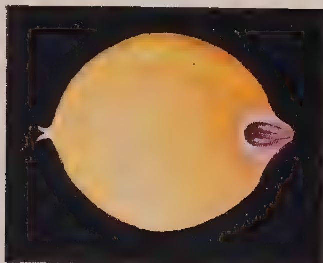
2. Brown



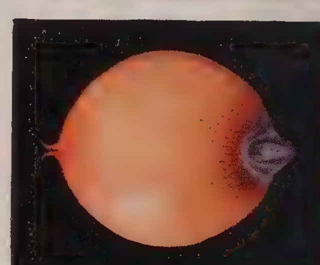
3. Light brown



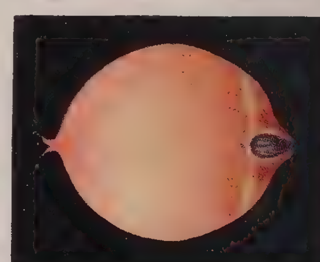
4. Yellow with brown wash



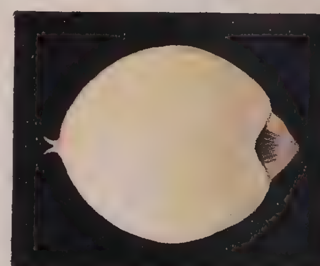
5. Yellow (no brown wash)



6. Red



7. Pink



8. White, pearly

9. White, chalky

Colour . . . . Reddish brown, brown, light brown, yellow (with or without brown-wash) red, pink and white (pearly or chalky) (Plate XXII)

Integument . . . Present or absent ; when present, brown or hyaline

Endosperm . . . . Mealy or horny

(Mention special features, if any, such as double seeds, dimpling, blotching, waxy endosperm, scent, popping quality, milling, baking and culinary attributes, etc.)

Physiological characters

i. Flowering duration
ii. Duration of crop
iii. Range of adaptability—season-bound or not
iv. Resistance to disease (if any)
v. Yield per acre—grain and straw (for strains)
vi. Special features like preference to particular soils, heavy rainfall or drought conditions

Flowering duration

This is to be expressed in days from the date of sowing to the day in which about half the population in a progeny row or plot have commenced to flower. This varies with the time of sowing and nature of season

Duration of crop

The number of days from sowing to ripe stage. This will vary with the time of sowing and seasonal conditions. The maturity of the grain has to be determined by testing grains from earheads. If the grains are hard and brittle they are considered to be mature. The date of maturity can only be approximate. Hence the number of days may be given to the nearest multiple of five

Quantitative characters

1. Height of plant
2. Number of leaves per plant
3. Leaf area per plant
4. Diameter of stalk
5. Length of peduncle
6. Thickness of peduncle
7. Length of panicle (earhead)
8. Diameter of panicle
9. Weight of panicle
10. Weight of grain per panicle
11. Number of grains in a panicle
12. Weight of 100 grains
13. Grain size

For uniformity in the measurement of the above characters, the following procedure may be observed in recording the measurements. Since all these characters are influenced by seasonal conditions, it is expected that the measurements will be recorded in a normal season for the area, on normal plants (not border plants) at maturity. All measurements to be recorded

in cm. and gm.—metric system. The average of 10 plants should be given with the standard error

1. Height : Height to be measured to the nearest multiple of 5 cm. from the base of the plant to the tip of the panicle. A measuring rod graduated in metres may be used. In the case of varieties with very loose panicles (*S. Roxburghii* var. *hians*) the measurement may be taken to the top of the earhead and in the case of varieties with recurved panicles (goose-neck) the height may be measured to the top of the loop

2. Number of leaves per plant : The number of distinguishable nodes above ground level to be counted. Each node has a leaf

3. Leaf area : The length and maximum breadth of the fourth leaf from the top to be measured. This will give a rough idea of leaf surface The fourth leaf from the top has proved a fair sample for this measurement

4. Diameter of stalk : The thickness at the middle of the fourth internode from the top measured with calipers

5. Length of peduncle : From the base of the panicle to the node below

6. Thickness of peduncle : This is to be measured 5 cm. below the ear head base, with calipers

7. Length of panicle : In panicles with erect branches the length to be measured from the basal whorl of branches to the tip of the panicle. In the case of loose panicles with drooping branches, the length of rachis to be recorded

8. Diameter of panicle : It is easier to take this measurement after the earhead is harvested. It can be measured by placing it across a metre scale and bringing together two blocks of wood with rectangular faces so as to touch the earhead on either side without pressing it, and the distance between the inner faces of the blocks read direct from the scale. This gives the maximum thickness of the panicle. This is to be recorded for panicles which have no drooping branches. In the case of the latter the length of the longest side branch may be recorded

9. Weight of panicle : Weight of earheads to be recorded in gm. The heads are to be cut with a stalk of 5 cm

10. Weight of grain per panicle : The earheads which are weighed are to be threshed separately by hand and the weight of grain to be recorded for all the 10 earheads

11. Number of grains per panicle : Eearheads with all grains intact to be taken. Usually in very compact earheads and very loose earheads with open glumes, grains shed when dry earheads are disturbed. Earheads are hence to be handled carefully and counts taken as early as possible after harvest Each earhead to be threshed separate and the grains counted

12. Weight of 100 grains : The grains from the earheads which were counted may be used. 100 grains from each head to be taken and weight recorded in gm.

13. Grain size : The length and maximum breadth of 100 grains from each earhead to be measured with calipers and the mean values given

Genetics of sorghum

Though sorghum is an ancient crop in India, particular attention has been bestowed on it only in recent years. The study of sorghum genetics is sti

in its infancy. Besides some agricultural research stations in India, its genetics is under study in some of the agricultural experiment stations in the United States of America also, where sorghum is gaining some importance as a dryland crop beacuse of its better drought-resistant qualities compared to maize.

In the United States Department of Agriculture Yearbook for 1936, Martin has recorded the genetics of certain characters, though till now some of them, on which this advance recording is made, have not been published. With regard to genic symbolization a certain amount of confusion is inevitable in the early stages. In a few cases the same symbol is used for different characters and in a few others different symbols have been given to the same character. With the increase in contact between co-workers, and with the further advance in the knowledge of the genetics of sorghum and their publication, this confusion will tend to decrease. The characters whose genetics have been reported so far are summarized in Appendix II and will help to this end. In some cases new genic symbols have now been given for characters whose inheritance has been reported.

REFERENCES

Conner, A. B. and Karper, R. E. (1923). Inheritance of seed-coat colour in certain crosses in grain sorghum. *J. Amer. Soc. Agron.* **15**, 338-44

Graham, R. J. D. (1916). Pollination and cross-fertilization in the *juar* plant (*Andropogon sorghum*). *Mem. Dept. agric. India Bot.* **8**, 201-5

Hilson, G. R. (1916). A note on the inheritance of certain stem characters in sorghum. *Agric. J. India*, **11**, 150-5

Karper, R. E. (1932). A dominant mutation of frequent recurrence in sorghum. *Amer. Nat.* **66**, 511-29

——— (1933). Inheritance of waxy endosperm in sorghum *J. Hered.* **24**, 257-62

Karper, R. E., Quinby, J. R. and Jones, D. L. (1938). Inheritance and improvement in sorghum. *Texas Agric. Exp. Sta. 51st. Ann. Rep.* 58

Karper, R. E., and Stephens, J. C. (1936). Floral abnormalities in sorghum. *J. Hered.* **27**, 183-94

Marcy, D. E. (1937). Inheritance of resistance to loose and covered smuts of sorghum. *Bull. Torrey bot. Cl.* **64**, 209-28 ; 245-67

Martin, J. H. (1936). *U. S. Dept. agric. Year Book* 1936, 554-5

Ramanathan, V. (1924). Some observations on mendelian characters in sorghum. *J. Madras agric. Stud. Un.* **12**, 1-17

Rangaswami Ayyangar, G. N. (1930). A graphic method of presenting simple mendelian segregation. *Agric. J. India*, **25**, 262-3

——— (1934). Recent work on the genetics of millets in India *Madras Agric. J.* **22**, 1-11

——— (1935). Juiciness and sweetness in sorghum stalks. *Madras Agric. J.* **23**, 350-2

——— (1939). Studies in sorghum. *J. Madras Univ.* **11**, 131-43

——— (1940). *Report on the work of the Agricultural Stations in the Madras Presidency for 1939-40*, p. 457

Rangaswami Ayyangar, G. N. and Ayyar, M. A. S. (1932). Inheritance of characters in sorghum, I. Chlorophyll deficiencies. *Indian J. agric. Sci.* **2**, 266-70

——— (1938). Linkage between a panicle factor and the pearly-chalky mesocarp factor (*Zz*) in sorghum. *Proc. Indian Acad. Sci.* **8**, 100-7

——— (1940). The inheritance and linkage affinities of the yellow coloured midrib in sorghum. *Curr. Sci.* **9**, 542 3

Rangaswami Ayyangar, G. N. Ayyar, M. A. S. and Nambiar, A. K. (1937). The inheritance of height *cum* duration in sorghum. *Madras. agric. J.* **25**, 107-18

Rangaswami Ayyangar, G. N., Ayyar, M A.S., and Nambiar, A.K. (1941). The inheritance of purple pigment at the base of anthers in sorghum. *Curr. Sci.* **10,** 491-2

Rangaswami Ayyangar, G. N., Ayyar, M. A. S. and Rao, V. P. (1934). Inheritance of characters in sorghum—the great millet. V. Linkage between sheath-glume and dry anther-grain colours. *Indian J. agric. Sci.* **4,** 90-5

——————(1937). Linkage between purple leaf-sheath colour and juiciness of stalk in sorghum. *Proc. Indian Acad. Sci.* **5,** 1-3

Rangaswami Ayyangar, G. N. ; Ayyar, M. A. S. Narayanan, T. R. and Nambiar, A. K. (1942). The grain sorghums of the durra group. *Proc. Indian Acad Sci.* **15,** 133-47

Rangaswami Ayyangar, G. N., Ayyar, M. A. S., Rao, V. P. and Nambiar, A. K. (1936). Inheritance of characters in sorghum—the great millet, IX. Dimpled grains. *Indian J. Agric, Sci.* **6,** 938-45

——————(1936, 2). Mendelian segregations for juiciness and sweetness in sorghum stalks. *Madras Agric. J.* **24,** 247-48

Rangaswami Ayyangar, G. N. and Nambiar, A. K. (1936). Inheritance of characters in sorghum—the great millet, VIII. A brownish purple mutant. *Indian J. agric. Sci.* **6,** 481-3

——————(1937). The relationship between the mechanical tissue brown factor and the factor for juiciness of stalk in sorghum *Madras Agric. J.* **25,** 157-8

——————(1938). A new factor determining the tint of red and yellow grain colours in sorghum. *Madras Agric. J.* **26,** 465-8

——————(1939). Genic differences govineing the distribution of stigmatic feathers in sorghum. *Curr. Sci.* **8,** 214-6

——————(1939). Lethal green seedlings in sorghum. *Curr. Sci.* **8,** 417-8

——————(1941, 1). The inheritance of the manifestation of purple colour at the pulvinar regions in the panicles of sorghum. *Curr. Sci.* **10,** 80-2

——————(1941, 2). The inheritance of depth of green colour in the leaves of sorghum. *Curr. Sci.* **10,** 492-3

Rangaswami Ayyangar, G. N. and Nambiar, K. K. (1938). A 'Tiny sorghum'. *Proc. Indian Acad. Sci.* **8,** 309-16

Rangaswami Ayyangar, G. N. and Ponnaiya, B. W. X. (1937,1). The occurrence and inheritance of earheads with empty anther sacs in sorghum. *Curr. Sci.* **5,** 390

——————(1937,2). The occurrence and inheritance of purple pigment on the glumes of sorghum close on emergence from the boot. *Curr. Sci.* **5,** 590

——————(1939,1). Hairiness of the midrib edges in sorghum. *Curr. Sci.* **8,** 115-6

——————(1939,2). The occurrence and inheritance of panicle tip sterility in sorghum. *Currert. Sci.* **8,** 116-7

——————(1939,3). Cleistogamy and its inheritance in sorghum. *Curr. Sci.* **8,** 418-9

——————(1939, 4). Studies in *Sorghum sudanense* Stapf—the Sudan grass. *Proc. Indian Acad. Sci.* **10,** 237-54

——————(1941, 1). The occurrence and inheritance of a bloomless sorghum. *Curr. Sci.* **10,** 408-9.

——————(1941, 2). The occurrence and inheritance of shoots from the axils of panicle branches in *Sorghum sudanense*. *Curr Sci.* **10,** 409-10

——————(1941, 3). Two new genes conditioning the tint of the colour on the glumes of sorghum. *Curr. Sci.* **10,** 410-1

——————(1941, 4). Wavy peduncle—the basic cause of goosenecking in sorghum. *Curr. Sci.* **10,** 528-30

——————(1941, 5). Sorghums with felty glumes. *Curr. Sci.* **10,** 533-4

Rangaswami Ayyangar, G. N. and Pannaiya, B. W. X. (1941, 6). Studies in *Sorghum halepense* (Linn.) Pers. the Johnson grass. *Proc. Indian Acad. Sci.* **13**, 157-62

Rangaswami Ayyangar, G. N. and Rao, V. P. (1935). Further data on the homology of stigmas and awns. *Curr. Sci.* **4**, 176-7

——— (1936, 1). *Sorghum papyrascens*, Stapf. *J. Indian Bot. Soc.* **15**, 139-42

———(1936, 2). Multiple seededness in sorghum and consequent repercussions. *Madras Agric. J.* **24**, 15-8

Rangaswami Ayyangar, G. N. Rao, V. P. and Nambiar, A. K. (1935, 1). Inheritance of characters in sorghum—the great millet, VII. Ligule and Auricle. *Indian J. agric. Sci.* **5**, 539-41

——— (1935, 2). The inheritance of some characters in crosses with the sorghums, Milo and Kafir. *Proc. Indian Acad. Sci.* **2**, 508-22

———(1939). The occurrence and inheritance of purple blotched grains in sorghum. *Curr. Sci.* **8**, 213-4

Rangaswami Ayyangar, G. N., Rao, V. P. Nambiar, A. K. and Ponnaiya, B. W. X. (1937). The occurrence and inheritance of waxy bloom on sorghum. *Proc. Indian Acad. Sci.* **5**, 4-15

Rangaswami Ayyangar, G. N., Rao, V. P. and Ponnaiya, B. W. X. (1936). Deciduous sessile spikelets. *Curr. Sci.* **5**, 299-300

——— (1938, 1). Green and bluish green seedlings in sorghum. *Curr. Sci.* **6**, 556-7

———(1938, 2). The occurrence and inheritance of purple tipped grains in sorghum. *Proc. Indian Acad. Sci.* **8**, 396-8

Rangaswami Ayyangar, G. N., Rao, V. P. and Reddy, T. V. (1937). The inheritance of deciduousness of the pedicelled spikelets of sorghum. *Curr. Sci.* **5**, 538-9

———(1938). The occurrence and inheritance of purple anthers in sorghum. *Proc. Indian Acad. Sci.* **8**, 317-23

Rangaswami Ayyangar, G. N. and Reddy, T. V. (1937). Chlorophyll deficiencies in sorghum Xantha and patchy albino. *Proc. Indian Acad. Sci.* **5**, 183-5

———(1938). The inheritance of basal feathered stigmas (and basal barbed subules) in sorghum. *Madras Agric. J.* **26**, 123-6

———(1939). The occurrence and inheritance of hairiness of leaf-tip in sorghum. *Madras Agric. J.* **27**, 210-4

———(1940, 1). The inheritance of a new type purple pigmentation manifesting on the glumes at anthesis. *Curr. Sci.* **9**, 228-9

———(1940, 2). The occurrence and inheritance of purple hairs on the spikelets of sorghum. *Curr. Sci.* **9**, 229

———(1940, 3). The inheritance of hairy styles (and barbed columns of awn) in sorghum. *Curr. Sci.* **9**, 282-3

———(1940, 4). Sorghum, awns of inconstant length and their inheritance. *Curr. Sci.* **9**, 283-4

———(1940, 5). Sorghum, spikelet-awn relationship and inheritance. *Madras Agric. J.* **28**, 306-8

Rangaswami Ayyangar, G. N., R ddy, T. V. and Ponnaiya, B. W. X. (1938). Sorghum —purple pigment in the late-seedling stage. *Curr. Sci.* **6**, 612-3

Rangaswami Ayyangar, G. N., Vijiaraghavan, C., Ayyar, M. A. S. and Rao, V. P. (1933). Inheritance of characters in sorghum—the great millet. III. Grain colours—red, yellow and white. *Indian J. agric. Sci.* **3**, 594-604

———(1934). Inheritance of characters in sorghum—the great millet. VI. Pearly and chalky grains *Indian J. agric. Sci.* **4**, 96-9

Rangaswami Ayyangar, G. N., Vijiaraghavan, C., Ayyar, M. A. S., Rao, V. P. and Subramanyam, P. (1934). Inheritance of characters in sorghum—the great millet, IV. Brown grains. *Indian J. agric. Sci.* **4**, 81-9

Rangaswami Ayyangar, G. N., Vijairaghavan, C., Pillai, V. G. and Ayyar, M. A. S. (1933). Inheritance of characters in sorghum—the great millet, II. Purple pigmentation on in leaf-sheath and glume. *Indian J. agric. Sci.* **3**, 589-94

Reed, G. M. (1930). A new method of production and detecting sorghum hybrids. *J. Hered.* **21**, 133-44

Sieglinger, J. B. (1924). Seed colour inheritance in certain grain sorghum crosses. *J. Agric. Res.* **27**, 53-64

——— (1929). Tennous Kafir plants. *J. Hered.* **20**, 565-6

——— (1932). Inheritance of height in Broom corn. *J. Agric. Res.* **44**, 13-20

——— (1933, 1). A dwarf mutation in Kafir. *J. Hered.* **24**, 337-8

——— (1933, 2). Inheritance of seed colour in crosses of brown seeded and white seeded sorghums. *J. Agric. Res.* **47**, 663-7

Sieglinger, J. B., Swanson, A. F. and Martin, J. H. (1934). Inheritance of awn development in sorghums. *J. Agric. Res.* **49**, 663-8

Snowden, J. D. (1936). *The Cultivated races of Sorghum.* Adlard & Son, Ltd., London

Stephens, J. C. (1937). Male sterility in sorghum. *J. Amer. Soc. Agron.* **29**, 690-6

——— and Quinby, J. R. (1938). Linkage of the Q B Gs group in sorghum. *J. Agric. Res.* **57**, 747-57

——— (1939). The D Rs P linkage group in sorghum. *J. Agric. Res.* **59**, 725-30

Swanson, A. F. (1928). Seed coat structure and inheritance of seed colour in sorghum. *J. Agric. Res.* **37**, 577-88

Swanson, A. F. and Parker, J. H. (1931). Inheritance of smut resistance and juiciness of stalk in sorghum. *J. Hered.* **22**, 51-6

Vinall, H. N. and Cron, A. B. (1921). Improvement of sorghums by hybridization. *J. Hered.* **12**, 435-43

Woodworth, C. M. (1936). Inheritance of seedling stem colour in a broom corn-sorghum cross. *J. Amer. Soc. Agron.* **28**, 325-7

APPENDIX I

Naming of the parts of the sorghum plant, pigmentation and other characters

Root (seedling): When seedlings about three weeks old are pulled out it will be observed that the roots are coloured purple in portions. This is due to anthocyanin pigmentation. The colour may be reddish purple, blackish purple or brown. The presence of pigmentation in the roots is inter related with the manifestation of coloured spots in the leaf sheath, leaf blade and glume of the mature plant (Plate XX).

Coleoptile or primary leaf-sheath: The pigmentation in the coleoptile can be noted soon after germination. It may be green or purple of grades. When the purple colour in the coleoptile is deep, the first two or three leaves of the seedling will also be purple coloured. This can be noted about two weeks after sowing. The pigmentation in the coleoptile is concurrent with the pigmentation in the leaf-sheath axil.

Leaf-sheath: In the young plants the leaf-sheath is green. As the plants mature purple or brown spots appear on the leaf-sheath and blade. These spots may be reddish purple, blackish purple or brown. The sheath of some varieties classed as reddish purple may be more red than purple or *vice versa*. These variations are due to the effect of other colour factors, such as those for grain pericarp colour.

Internodes: The internodes are partly or fully enclosed by the leaf-sheath. They are usually green with a coating of ashy bloom which is prominent in exposed parts. In plants with purple leaf-junctions, the exposed parts of the internodes are purple coloured. This can be noted clearly at flowering time in the lower internodes which may be exposed fully by the leaf-sheath peeling off due to desiccation.

Nodal band: This term is used to denote the swollen ring at the base of the leaf-sheath just above its point of attachment with the stem. This is referred to as 'sheath node' by Snowden. When the coleoptile is deep purple and the leaf-junctions are purple the nodal band is also coloured purple. Another kind of colour manifestation which is dull purple in the early stages, turns darker and has a reticulated appearance in older plants. This is associated with a sienna-coloured dry anther and a good yellow grain.

Leaf-axil : The term axil refers to the inside basal part of the leaf-sheath above the nodal band. The axil may be purple coloured or green. When purple, the colour will be prominent in the middle of the leaf-sheath base.

Leaf junction : This refers to the two light-coloured triangular bits of tissue at the junction of the leaf-sheath and leaf-blade. These may be green or coloured purple. This is best noted in young plants and up to flowering time.

Glume tips : In most varieties the tips of the glumes are purple at about the flowering time of the spikelets. This is best observed after the earhead has fully emerged from the boot (final leaf-sheath) and the spikelets are about to open.

Glumes : Glumes are usually green at the time of emergence of the earhead from its boot. After the flowering of the spikelets, as the grains mature the glumes change into various colours such as red, chocolate, brown, purple or black of shades. In some the colour will be confined to a narrow band at the base of the glumes, the rest being brownish yellow or straw coloured. In varieties without purple pigment the whole glume will be straw coloured. Though shades of red and black tend to merge with each other, they are separable with the help of their respective leaf-sheath colours.

The glumes in the mature spikelets are usually smooth, rounded and convex. In some races (*Sorghum cernum* Host and *S. subglabrescens* Schienf. *et* Aschers) a transverse wrinkle is found about the middle of the glumes as the spikelet matures. This may be formed in both the glumes or in the upper glume only, the lower one being not wrinkled.

Usually the glumes in the mature earhead appear to clip the grains enclosing them wholly or partly. In certain varieties (*S. Roxburghii* var. *hians* Stapf) the glumes open out with their edges rolled in as the spikelets mature. Such a condition is termed 'gaping' glumes. In varieties with gaping glumes the grains are fully exposed and therefore easily shed.

Stigma : The colour of the fresh stigma (axis and feathers) varies from a hyaline condition to good yellow. As the spikelets open in the early hours of the morning, the fresh stigma colour should be observed then (8—10 a.m.). This is an important character as it is related to grain pericarp colour. A hyaline stigma indicates a white grain and a yellow stigma a coloured grain.

Anther : The fresh anther colour is best observed in the morning in newly opened spikelets. The anthers are usually yellow varying in depth from a cream colour to good yellow. As they dry up they change colour to shades of brown, red or sienna or a combination of these colours. The change is gradual, the colour increasing in depth day by day and in some varieties the final colour is attained only four or five days after the flowering of the spikelet (Plate XXI).

Hairiness : Minute hairs occur in various parts of the sorghum plant. The more important of these are at the nodal band, leaf-junction, rachis of the panicle and glume. In the case of the leaf-junction the anterior side is always hairy, while the posterior side may be glabrous in some varieties. The nodal bands may be hairy or glabrous and so also the glumes. When the nodal band is glabrous, the posterior side of the junction will be glabrous and the glume also may be glabrous or sparsely hairy. The hairs on the glumes may be dense and over the entire surface or they may be sparse. In sparse hairy types, the hairs occur on the upper half of the glumes and along their edges. Hairiness is best observed when the plants are in the flowering phase. At this stage the nodes are usually exposed and the glumes also could be easily examined. Moreover as the plant matures and gets desiccated, hairs sometimes drop off. In odd varieties hairs are dense and long and give a felty appearance.

Bloom : This term is used for the waxy covering on leaf-sheath and internodes, appearing as an ashy coating. The deposit is usually present and may be heavy or sparse.

Stem juiciness : The stalks in all sorghum varieties contain considerable juice before maturity. As the plant matures the juice content is reduced. In certain varieties the stem is juicy even at ripe stage of the plant, while in others it is almost dry. The juicy or pithy condition of the stem is indicated by the midrib of the leaf. The midrib is dull green when the stem is juicy and it is white when the stem is pithy (dry). Even in pithy stalks the basal internodes will contain some juice which can be pressed out. For determining taste of the stalk in pithy varieties these basal internodes will have to be taken.

The taste of the juice also varies in different varieties. Some are very sweet, while some are quite insipid. The differences are due to variations in the sugar content of the juice. For purposes of description the relative sweetness may be determined by tasting.

Midrib : The midrib of the leaf in the adult plant is usually white or dull green. In a few varieties it may be yellowish.

Panicle : The sorghum panicle is of various shapes, sizes and densities. The descriptive notes about a panicle coupled with the measurements recorded under quantitative characters will only give a rough idea of the nature of the panicle. Panicle notes should be recorded at maturity, as newly emerged panicles change shape during flowering and ripening. The emergence may be good or poor. If poor, how the head emerges and frees itself from the boot, may be noted.

Awn : The awn in sorghum, when present, is an appendage to the upper lemma in the spikelet. The base of the awn is attached to the middle of the lemma. The length may vary from 1 to 15 mm. When the awns are long—more than 5 or 6 mm.—they are twisted and bent about the middle. The awn length is best recorded soon after the emergence of the earhead and before the spikelets commence to flower. At this stage the awns are mostly straight, the bending and twisting developing only later.

Grain : The exposure of the grain in the panicle is an important varietal characteristic. The grain may be completely enclosed in the glumes, exposed a little at the top, much exposed and project beyond the glumes, but tightly clasped by them, and much exposed and free from the glumes which open out (gape).

The size of the grain varies widely. For descriptive purposes those that do not pass through a sieve with 1/8-in. holes may be classed as bold, those passing through 1/8-in. sieve but not passing through 1/10-in. holes as medium, and grains that pass through 1/10-in. sieve as small.

The shape of the grain as observed from the hilum side is usually obovate ; some grains are ovate or elliptic or orbicular. The grains also differ in their thickness. Some are thick and prominently lens-shaped, while others may be flattish.

The common colours met with are reddish brown, brown, light brown, red, yellow with brown wash, good yellow (without brown wash), white pearly and white chalky. Some white-seeded varieties may have red wash or red or brown spots, and they may also have a tinge of red or yellow colour at their base on the scutellum and round the hilum (areas enclosed within the glumes).

In some sorghums the integument (nucellus) may persist and it is usually coloured brown. This can be observed by gently scraping the seed-coat.

The endosperm is usually starchy. This may consist of an outer horny portion and an inner soft mealy portion. The relative thickness of these two varies in different varieties. Bold grains have usually a greater soft mealy endosperm and small grains more of horny endosperm.

A. Characters, their genes and mode of inheritance

Plant part	Characters		Symbols*	Ratio	Authority and date published or reported
	Dominant	Recessive			
1	2	3	4	5	6
Seedling—					
Coleoptile	Red	Green	R—r	3 : 1	Reed [1930], Karper and Conner [1930]; Martin [1936]; Rangaswami Ayyangar [1930]
Ditto	Purple	Ditto	Pc—pc	3 : 1	Rangaswami Ayyangar [1939]
Stem	Red	Ditto	...	9 : 7	Woodworth [1936]
Ditto	Ditto	Ditto	Rs—rs	3 : 1	Stephens and Quinby [1939]
Chlorophyll	Normal (green)	White	$W_1 w_1$ to $W_4 w_4$	3 : 1	Karper and Conner [1930]; Martin [1936]
Ditto	Ditto	Ditto	$W_5 w_5$ to $W_{12} w_{12}$	3 : 1	Quinby and Karper [1934]; Martin [1936]
Ditto	Ditto	White (lethal)	...	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Virescent white	$V_1 v_1$ and $V_2 v_2$	3 : 1	Karper and Conner [1930]; Martin [1936]
Ditto	Ditto	Ditto	$V_3 v_3$ to $V_8 v_8$	3 : 1	Quinby and Karper [1934]; Martin [1936]
Ditto	Ditto	Ditto	...	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Yellow	$Y_1 y_1$ to $Y_4 y_4$	3 : 1	Karper and Conner [1930]; Martin [1936]
Ditto	Ditto	Ditto	$Y_5 y_5$ and $Y_6 y_6$	3 : 1	Quinby and Karper [1934]; Martin [1936]
Ditto	Ditto	Pale green (lethal)	...	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Ditto	$Pg_1 pg_1$ to $Pg_3 pg_3$	3 : 1	Quinby and Karper [1933]; Martin [1936]
Ditto	Ditto	Pale green (lingering)	...	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Pale green (surviving)	...	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Lethal green	Cl—Cl	3 : 1	Rangaswami Ayyangar and Nambiar [1939]
Ditto	Ditto	Xantha	Yx—yx	3 : 1	Rangaswami Ayyangar and Reddy [1937]
Ditto	Ditto	Patchy albino	Alp—alp	3 : 1	Rangaswami Ayyangar and Reddy [1937]
Ditto	Ditto	Banded	Cb—cb	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Ditto	Ditto	Patchy pale	...	3 : 1	Rangaswami Ayyangar [1939]

* Old genic symbols with all capital letters have now been changed to first letter capital and the rest small.

APPENDIX II—*contd.*

Plant part	Characters		Symbols*	Ratio	Authority and date published or reported
	Dominant	Recessive			
1	2	3	4	5	6
Chlorophyll	Bluish green	Green (glossy)	Cbl—cbl	3 : 1	Rangaswami Ayyangar *et al.* [1938]; Karper *et al.* [1938]
Seedling	Late purple	Green	Pls—pls	3 : 1	Rangaswami Ayyangar *et al.* [1938]
Plant colour	Purple (leaf-sheath and glume)	Brown	P—p	3 : 1	Rangaswami Ayyangar *et al.* [1933]
Ditto	Reddish purple (leaf-sheath and glume)	Blackish purple	Q—q	3 : 1	Rangaswami Ayyangar *et al.* [1933]
Ditto	Green internode	Brownish purple	Mtb—mtb	3 : 1	Rangaswami Ayyangar and Nambiar [1936]
Ditto	Green stems and leaves	Red	Cr—cr	3 : 1	Stephens and Quinby [1931]; Martin [1936]
Ditto	Ditto	Yellow	Cy_1—cy_1	3 : 1	Stephens and Quinby [1932]; Martin [1936]
Ditto	Ditto	Ditto	Cy_2—cy_2	3 : 1	Stephens and Quinby [1933]; Martin [1936]
Ditto	Ditto	Golden	Cg—cg	3 : 1	Stephens and Quinby [1932]; Martin [1936]
Ditto	Colourless mechanical tissue	Brownish yellow	...	9 : 7	Rangaswami Ayyangar [1939]
Stalk	Normal thickness (kafir)	Tenuous	...	3 : 1	Siegliner [1929]
Ditto	Pithy	Juicy	D—d	3 : 1	Hilson [1916]; Swanson and Parker [1931]; Rangaswami Ayyangar [1935]
Ditto	Insipid	Sweet	X—x	3 : 1	Rangaswami Ayyangar *et al.* [1936]
Ditto	Bloom present	Bloom absent	Bm—bm	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
Ditto	Bloom heavy	Sparse	H—h	3 : 1	Rangaswami Ayyangar *et al.* [1937]
Nodal band	Purple	Green	Pj—pj	3 : 1	Rangaswami Ayyangar [1934]
Ditto	Reticulated purple	Ditto	Nr—nr	3 : 1	Rangaswami Ayyangar [1934]
Ditto	Hairy	Glabrous	Nh—nh	3 : 1	Rangaswami Ayyangar [1934]
Leaf	Dark green	Lighter shades	C_1 c_1 and C_2 c_2	3 : 1	Rangaswami Ayyangar [1939]; Rangaswami Ayyangar and Nambiar [1941]
[illegible]	[illegible]	[illegible]	[illegible]	3 : 1	Quinby and Karper [1934]; Martin [1936]

Ditto	Ditto	Zebra	Z—z	3 : 1	Quinby and Karper [1934]; Martin [1936]
Ditto	Ditto	Green striped	Gs—gs	3 : 1	Stephens and Quinby [1938]
Ditto	Ditto	Striped (longitudinal)	Cs—cs	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Ditto	Wavy	Flat	Mu—mu	3 : 1	Rangaswami Ayyangar *et al.* [1935]
Ditto	Margin non-drying	Drying	Md—md	3 : 1	Rangaswami Ayyangar *et al.* [1935]
Leaf	Tip non-drying	Drying	...	3 : 1	Rangaswami Ayyangar [1939]
Ditto	Tip hairy	Glabrous	Lh—lh	3 : 1	Rangaswami Ayyangar and Reddy [1939]
Ditto	Midrib normal	Weak	Md—md	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Leaf—					
Midrib	Yellow	Non-yellow	Ymd—ymd	3 : 1	Martin [1931]; Martin [1936]; Rangaswami Ayyangar and Ayyar [1940]
Ditto	Hairy edges	Hairless	Mdh—mdh	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Junction	Present and ligulate	Absent and e-ligulate	Lg—lg	3 : 1	Rangaswami Ayyangar *et al.* [1935]
Ditto	Smooth	Corrugated	Jc—jc	3 : 1	Rangaswami Ayyangar *et al.* [1935]
Ditto	Broad	Narrow	...	3 : 1	Rangaswami Ayyangar [1939]
Junction and node	Purple	Green	Pj—pj	3 : 1	Rangaswami Ayyangar [1939]
Axil	Purple	Green	...	9 : 7	Rangaswami Ayyangar [1939]
Panicle—					
Peduncle	Straight	Wavy	Wy—wy	3 : 1	Rangaswami Ayyangar [1939]; Rangaswami Ayyangar and Ponnaiya [1941]
Ditto	Loose	Compact	...	3 : 1	Ramanathan [1924]; Parker [1927]; Martin [1936]; Rangaswami Ayyangar [1934]
Ditto	Loose conical	Compact spindle	Pa_1—pa_1	3 : 1	Rangaswami Ayyangar and Ayyar [1934]
	Acicular spindle	Oval	...	3 : 1	Rangaswami Ayyangar [1939]
	Medium compact	Compact	...	3 : 1	Rangaswami Ayyangar [1939]
	Short branches	Long branches	...	3 : 1	Karper [1931]; Martin [1936]
	Short rachis	Long rachis	...	3 : 1	Karper [1931]; Martin [1936]
	Few nodes	Many nodes	...	3 : 1	Karper [1931]; Martin [1936]
	Pulvinate and divergent secondary branches	E-pulvinate and adpressed	Pa_2—pa_2	3 : 1	Rangaswami Ayyangar and Ponnaiya [1937]

* Old genic symbols with all capital letters have now been changed to first letter capital and the rest small

APPENDIX II—*contd.*

Plant part	Characters		Symbols*	Ratio	Authority and date published or reported
	Dominant	Recessive			
1	2	3	4	5	6
Panicle	Pulvinus purple	No purple	Px—px	3 : 1	Rangaswami Ayyangar and Nambiar [1941]
Ditto	Normal tip	Sterile tip	Pats—pats	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Ditto	Normal	Shoots from axils of branches	...	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
Spikelets—					
Sessile	Small ovate with short awn	Big elliptic with long awn	...	3 : 1	Rangaswami Ayyangar and Reddy [1940]
Ditto	Normal	Bulbils	...	3 : 1	Rangaswami Ayyangar [1939]
Ditto	Purple hairs	Hyaline hairs	Ph—ph	3 : 1	Rangaswami Ayyangar and Reddy [1940]
Ditto	Non-shedding	Shedding	Sh—sh	3 : 1	Rangaswami Ayyangar *et al.* [1936]
Pedicelled	Persistent	Deciduous	Sh_1—sh_1	3 : 1	Rangaswami Ayyangar *et al.* [1937]
Ditto	Purple wash	Green	Pw—pw	3 : 1	Rangaswami Ayyangar and Ponnaiya [1938]
Glume	Purple at emergence	No purple	Gep—gep	3 : 1	Rangaswami Ayyangar and Ponnaiya [1937]
Ditto	Green at anthesis	Purple at anthesis	...	3 : 1	Rangaswami Ayyangar and Reddy [1940]
Ditto	Coriaceous—both glumes	Papery	Py—py	3 : 1	Rangaswami Ayyangar and Rao [1936]
Ditto	Ditto	Lower glume only papery	...	3 : 1	Rangaswami Ayyangar [1939]
Ditto	Ditto	Thinly crustaceous	...	3 : 1	Rangaswami Ayyangar [1939-40]
Ditto	Purple (mature)	No purple	P—p	3 : 1	Rangaswami Ayyangar *et al.* [1933]
Ditto	Red (mature)	No red (black)	Q—q	3 : 1	Rangaswami Ayyangar *et al.* [1933]; Vinall and Cron [1921]
Ditto	Ditto	Black	Gb—gb	3 : 1	Stephens and Quinby [1931]; Martin [1936]
Ditto	Black (mature)	Red	Gr—gr	3 : 1	Stephens and Quinby [1931]; Martin [1936]
Ditto	Ditto	Straw colour	Gs—gs	3 : 1	Stephens and Quinby [1931]; Martin [1936]
Ditto	Deep coloured	Dilute	Cd—cd	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
Ditto	Bleached	Deep coloured	Cl—cl	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]

					[1934]
Ditto	Edges not rolled in	Edges rolled in	Gx—gx	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Glume	Hairy	Glabrous	Gh—gh	3 : 1	Ramanathan [1924]; Rangaswami Ayyangar [1939]; Rangaswami Ayyangar and Ponnaiya [1941]
Ditto	Long hairs (felty)	Short hairs	Gf—gf	3 : 1	Rangaswami Ayyangar [1939]; Rangaswami Ayyangar and Ponnaiya [1941]
Ditto	Wrinkled	Smooth	...	3 : 1	Ramanathan [1924]
Ditto	Wrinkled (both)	Not wrinkled (both)	...	9 : 7	Rangaswami Ayyangar [1939]
Ditto	Ditto	Upper only wrinkled	...	3 : 1	Rangaswami Ayyangar *et al.* [1942]
Awn	Awnless	Awned	A—a	3 : 1	Vinal and Cron [1921]; Ramanathan [1924] Sieglinger [1933]; Sieglinger *et al.* [1934] Rangaswami Ayyangar [1934]
Ditto	Ditto	Tip awn	A—at	3 : 1	Sieglinger *et al.* [1934]
Ditto	Awned	Ditto	a—at	1 : 2 : 1	Sieglinger *et al.* [1934]; Rangaswami Ayyangar [1934]
Awn	Constant length awn	Inconstant	Ai—ai	3 : 1	Rangaswami Ayyangar and Reddy [1940]
Ditto	Purple tips	No purple	Ap—ap	3 : 1	Rangaswami Ayyangar *et al.* [1935]
Anther	Normal	Antherless	Al—al	3 : 1	Stephens *et al.* [1933]; Martin [1936]
Ditto	Normal (with pollen)	Empty (no pollen)	Ms—ms	3 : 1	Rangaswami Ayyangar and Ponnaiya [1937], Stephens [1937]
Ditto	Normal pollen	Empty pollen	Me—me	3 : 1	Rangaswami Ayyangar [1939]
Anther (fresh)	Yellow	Purple blotched	As—as	3 : 1	Rangaswami Ayyangar [1939]
Ditto	Purple base	No purple	Ab—ab	3 : 1	Rangaswami Ayyangar [1934]; Rangaswami Ayyangar *et al.* [1941]
Ditto	Purple	Yellow	Pan—pan	3 : 1	Rangaswami Ayyangar *et al.* [1938]
Ditto	Yellow	Light purple wash	...	3 : 1	Rangaswami Ayyangar [1939-40]
Anther (dry)	Brick red tan	Tan	R—r	3 : 1	Graham [1916]; Sieglinger [1933]
Ditto	Red	No red	R—r	3 : 1	Rangaswami Ayyangar *et al.* [1933]
Ditto	Brown	No brown (sienna)	B_1b_1—B_2b_2	3 : 1	Rangaswami Ayyangar *et al.* [1934]
Anther-filament	Normal length	Reduced	Fr—fr	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
Stigma	Purple	No purple	Ps—ps	3 : 1	Rangaswami Ayyangar [1939-40]
Ditto	Feathers bushy	Sparse	Sb—sb	3 : 1	Rangaswami Ayyangar and Nambiar [1939]

*Old gentic symbols with all capital letters haxe now been changed to first letter capital and the rest small

APPENDIX II—*contd.*

Plant part	Characters		Symbols*	Ratio	Authority and date published or reported
	Dominant	Recessive			
1	2	3	4	5	6
Stigma	Fully feathered	Basal feathered	Stbf—stbf	3 : 1	Rangaswami Ayyangar and Reddy [1938]
Ditto	Hairy, style and awn columns barbed	Smooth and awn columns smooth	Bc—bc	3 : 1	Rangasawmi Ayyangar and Reddy [1940]
Seed	Pericarp colour yellow	No yellow (white)	Y—y	3 : 1	Graham [1916]
Ditto	Pericarp colour red	No red	R—r	3 : 1	Graham [1916]; Rangaswami Ayyangar *et al.* [1933]
Ditto	Pericarp colour brown	No brown	B_1b_1—B_2b_2	9 : 7	Rangaswami Ayyangar *et al.* [1934]
Ditto	Pericarp colour intensified	Not intensified (light)	I—i	3 : 1	Rangaswami Ayyangar *et al.* [1933]
Ditto	Pericarp whole coloured	Base only coloured	W—w	3 : 1	Rangaswami Ayyangar *et al.* [1933]
Ditto	Wash on pericarp	No wash	M—m	3 : 1	Rangaswami Ayyangar and Nambiar [1938]
Ditto	Purple blotched	No purple	Pb—pb	3 : 1	Rangaswami Ayyangar *et al.* [1939]
Ditto	Purple tip	No purple tip	Pgt—pgt	3 : 1	Rangaswami Ayyangar *et al.* [1938]
Ditto	Shape umbonate	Round top	U—u	3 : 1	Rangaswami Ayyangar *et al.* [1935]
Ditto	Normal	Dimpled	Dp—dp	3 : 1	Rangaswami Ayyangar *et al.* [1936]
Ditto	Thin mesocarp (pearly)	Thick mesocarp (chalky)	Z—z	3 : 1	Rangaswami Ayyangar *et al.* [1934]
Ditto	Thick mesocarp (spreader)	Thin mesocarp	S—s	3 : 1	Sieglinger [1924]
Ditto	Nucellar layer present (brown)	Absent	B—b	3 : 1	Sieglinger [1924]; Swanson [1929]
Litto	Endosperm—starchy	Sugary	Su—su	3 : 1	Karper [1933]; Martin [1936]
Ditto	Ditto	Waxy	Wx—wx	3 : 1	Karper [1933]; Martin [1936]
Ditto	Ditto	Ditto	...	15 : 1	Rangaswami Ayyangar [1939]
Ditto	Not scented	Scented	Sc—sc	3 : 1	Rangaswami Ayyangar [1939]
Ditto	Single	Double (connate)	Co—co	3 : 1	Rangaswami Ayyangar [1939]
Ditto	Double (multiflorus)	Single	Ts—ts	3 : 1	Karper and Stephens [1936]; Rangaswami Ayyangar and Rao [1936]; Stephens and

Plant height and duration	Tall (kafir)	Normal	T—t	3 : 1	Karper [1932]
Ditto	Normal (kafir)	Double dwarf	...	3 : 1	Sieglinger [1933]
Ditto	Standard (milo)	Dwarf	D_1—d_1	3 : 1	Karper [1930]
Ditto	Dwarf (milo)	Double dwarf	D_2—d_2	3 : 1	Karper [1930]
Ditto	Standard broom corn	Western dwarf	A—a	3 : 1	Sieglinger [1932]
Ditto	Standard broom corn	Japanese dwarf	D—d	3 : 1	Sieglinger [1932]
Ditto	Tall (*S. Roxburghii*)	Dwarf	...	3 : 1	Rangaswami Ayyangar [1934]
Ditto	Short—early (durra)	Tall—late	In_1—in_1	3 : 1	Rangaswami Ayyangar *et al.* [1937]
Ditto	Late	Early	E—e	3 : 1	Stephens and Quinby [1931]; Martin [1936]; Karper [1932]; Martin [1936]
Habit	Spreading	Erect	So—so	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Ditto	Tillering	Single stalked	Tx—tx	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Ditto	Delayed tillering	Uniform tillering	Tu—tu	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Ditto	Normal kafir	Midget	M—m	3 : 1	Quinby and Karper; Martin [1936]
Ditto	Normal plant	Tiny plant	Inty—inty	3 : 1	Rangaswami Ayyangar and Nambiar [1938]
Disease resistance— Smut	Susceptibility	Resistance	K—k	3 : 1	Reed [1930]; Martin [1936]; Swanson and Parker [1931]
Ditto	Ditto	Ditto	S—s	3 : 1	Marcy [1937]
Ditto	Resistance	Susceptibility (milo)	R—r	3 : 1	Reed [1930]; Marcy [1937]
Ditto	Ditto	Susceptibility (feterita)	B—b	3 : 1	Marcy [1937]
Red spot	Susceptibility	Resistance	...	3 : 1	Swanson and Parker [1932]; Martin [1936]
Root rot	Ditto	Ditto	...	3 : 1	Bowman *et al.* [1934]; Martin [1936]

*Old genic symbols with all capital letters have now been changed to first letter capital and the rest small

APPENDIX II—*contd.*

B. Genes in alphabitical order

Symbols*	Plant part	Characters		Ratio	Authority and date published or reported
		Dominant	Recessive		
1	2	3	4	5	6
A—a	Plant height	Standard broom corn	Western dwarf	3 : 1	Sieglinger [1932]
A—a	Awn	Awnless	Awned	3 : 1	Vinall and Cron [1921]; Ramanathan [1924]; Sieglinger *et al.* [1934]; Rangaswami Ayyangar [1934]
A—a^t	Awn	Ditto	Tip awn	3 : 1	Sieglinger *et al.* [1934]
a—a^t	Awn	Awned (weak awn*)	Do.	1 : 2* : 1	Sieglinger *et al.* [1934]; Rangaswami Ayyangar [1934]
Ab—ab	Anther	Purple base	No purple	3 : 1	Rangaswami Ayyangar [1934]; Rangaswami Ayyangar *et al.* [1941]
Ai—ai	Awn	Constant length	Inconstant	3 : 1	Rangaswami Ayyangar and Reddy [1940]
Al—al	Anther	Normal	Antherless	3 : 1	Stephens *et al.* [1933]; Martin [1936]
Alp—alp	Chlorophyll of seedling	Normal green	Patchy albino	3 : 1	Rangaswami Ayyangar and Reddy [1937]
Ap—ap	Awn	Purple tips	No purple	3 : 1	Rangaswami Ayyangar *et al.* [1935]
As—as	Anther	Normal yellow	Purple blotched	3 : 1	Rangaswami Ayyangar [1939]
B—b	Seed	Nucellar layer present (brown)	Absent	3 : 1	Sieglinger [1924]; Swanson [1929]
B—b	Disease resistance	Smut resistance	Susceptibility (feterita)	3 : 1	Marcy [1937]
B_1 & B_2—b_1 & b_2	Anther (dry)	Brown	No brown (sienna)	3 : 1	Rangaswami Ayyangar *et al.* [1934]
B_1 & B_2—b_1 & b_2	Seed pericarp colour	Brown	No brown	9 : 7	Rangaswami Ayyangar *et al.* [1934]
Bc—bc	Style and awn	Style hairy and awn columns barbed	Style and awn columns smooth	3 : 1	Rangaswami Ayyangar and Reddy [1940]
Bm—bm	Stalk	Bloom present	Bloom absent	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
C_1 & C_2—c_1 & c_2	Leaf—colour	Dark green	Light green	3 : 1	Rangaswami Ayyangar [1939]; Rangaswami Ayyangar and Nambiar [1941]
Cb—cb	Chlorophyll in seedlings	Normal green	Banded	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Cbl—cbl	Ditto	Bluish green	Green	3 : 1	Rangaswami Ayyangar *et al.* [1938]; Karper *et al.* [1938]
Cd—cd	Glume	Deep coloured	Dilute colour	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]

Cl—cl	Glume	Bleached	Coloured	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
Cl—cl	Chlorophyll in seedlings	Normal green	Lethal green	3 : 1	Rangaswami Ayyangar and Nambiar [1939]
Co—co	Seed	Single	Connate Double	3 : 1	Rangaswami Ayyangar [1939]
Cr—cr	Stem and leaves	Green	Red	3 : 1	Stephens and Quinby [1931] ; Martin [1936]
Cs—cs	Leaf	Normal green	Striped (longitudinal)	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Cy_1—cy_1	Stems and leaves	Green	Yellow	3 : 1	Stephens and Quinby [1932] ; Martin [1936]
Cy_2—cy_2	Ditto	Ditto	Yellow	3 : 1	Stephens and Quinby [1933] ; Martin [1936]
D—d	Plant height	Standard broom corn	Japanese dwarf	3 : 1	Sieglinger [1932]
D—d	Stalk	Pithy	Juicy	3 : 1	Hilson [1916] ; Swanson and Parker [1931]; Rangaswami Ayyangar [1935]
D_1—d_1	Plant height	Standard (milo)	Dwarf	3 : 1	Karper [1930]
D_2—d_2	Ditto	Dwarf (milo)	Double dwarf	3 : 1	Karper [1930]
Dp—dp	Seed	Normal	Dimpled	3 : 1	Rangaswami Ayyangar [1936]
E—e	Duration	Late	Early	3 : 1	Stephens and Quinby [1931] ; Martin [1936]; Karper [1932] ; Martin [1936]
F_1—f_1	Leaf	Normal	Fired	3 : 1	Quinby and Karper [1934] ; Martin [1936]
Fr—fr	Anther	Normal length filament	Reduced filament	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
Gb—gb	Glume	Red (mature)	Black	3 : 1	Stephens and Quinby [1931] ; Martin [1936]
Gep—gep	Ditto	Purple at emergence	No purple	3 : 1	Rangaswami Ayyangar and Ponnaiya [1938]
Gf—gf	Ditto	Long hairs (felty)	Short hairs	3 : 1	Rangaswami Ayyangar [1939] ; Rangaswami Ayyangar and Ponnaiya [1941]
Gh—gh	Ditto	Hairy	Glabrous	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
Gr—gr	Ditto	Black (mature)	Red	3 : 1	Stephens and Quinby [1931] ; Martin [1936]
Gs—gs	Ditto	Ditto	Straw colour	3 : 1	Stephens and Quinby [1931] , Martin [1936]
Gs—gs	Leaf	Normal green	Green striped	3 : 1	Stephens and Quinby [1938]
Gx—gx	Glume	Edges not rolled in	Edges rolled in	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
H—h	Stalk	Heavy bloom	Sparse bloom	3 : 1	Rangaswami Ayyangar *at al.* [1937]
I—i	Seed	Pericarp colour intensified	Not intensified (light)	3 : 1	Rangaswami Ayyangar *et al.* [1933]
In_1—in_1	Plant height and duration	Short—early (durra)	Tall—late	3 : 1	Rangaswami Ayyangar *et al.* [1937]
Inty—inty	Habit	Normal	Tiny	3 : 1	Rangaswami Ayyangar and Nambiar [1938]
Jb—jb	Leaf—junction	Broad	Narrow	3 : 1	Rangaswami Ayyangar [1939]

*Old genic symbols with all capital letters have now been changed to first letter capital and the rest small

APPENDIX II—*contd.*

Symbols *	Plant part	Characters: Dominant	Characters: Recessive	Ratio	Authority and date published or reported
1	2	3	4	5	6
Jc—jc	Leaf—junction	Smooth	Corrugated	3 : 1	Rangaswami Ayyangar *et al.* [1935]
K—k	Disease resistance—smut	Susceptibility	Resistance	3 : 1	Reed [1930];—Martin [1936]; Swanson and Parker [1931]
Lg—lg	Leaf—junction	Present and ligulate	Absent and e-ligulate	3 : 1	Rangaswami Ayyangar *et al.* [1935]
Lh—lh	Leaf—tip	Hairy	Glabrous	3 : 1	Rangaswami Ayyangar and Reddy [1939]
M—m	Seed	Pericarp colour—wash on pericarp	No wash	3 : 1	Rangaswami Ayyangar and Nambiar [1938]
M—m	Habit	Normal kafir	Midget	3 : 1	Quinby and Karper; Martin [1936]
Md—md	Leaf—margin	Non-drying	Drying	3 : 1	Rangaswami Ayyangar *et al.* [1935]
Md—md	Leaf–midrib	Normal	Weak	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Mdh—mdh	Ditto	Hairy edges	Hairless	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Me—me	Anther	Normal pollen	Empty pollen	3 : 1	Rangaswami Ayyangar [1939]
Ms—ms	Ditto	Normal (with pollen)	Empty (without pollen)	3 : 1	Rangaswami Ayyangar and Ponnaiya [1937] and Stephens [1937]
Mtd—mtd	Internode	Green	Brownish purple	3 : 1	Rangaswami Ayyangar and Nambiar [1936]
Mu—mu	Leaf	Wavy	Flat	3 : 1	Rangaswami Ayyangar *et al.* [1935]
Nh—nh	Nodal band	Hairy	Glabrous	3 : 1	Ramanathan [1924]; Rangaswami Ayyangar and Reddy [1939]
Nr—nr	Ditto	Reticulated purple	Green	3 : 1	Rangaswami Ayyangar [1934; 1939]
P—p	Leaf—sheath and glume (mature)	Purple	Brown	3 : 1	Rangaswami Ayyangar *et al.* [1933]
Pa_1 — pa_1	Panicle	Loose conical	Compact spindle	3 : 1	Rangaswami Ayyangar and Ayyar [1934]
Pa_2— pa_2	Ditto	Pulvinate and divergent secondary branches	E-pulvinate and adpressed	3 : 1	Rangaswami Ayyangar and Ponnaiya [1937]
Pa_{ts}—pa_{ts}	Ditto	Normal tip	Sterile tip	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Pan—pan	Anther	Purple	Yellow	3 : 1	Rangaswami Ayyangar *et al.* [1938]
Pb—pb	Seed	Pericarp purple blotched	No purple blotches	3 : 1	Rangaswami Ayyangar *et al.* [1939]
Pc—pc	Coleoptile and leaf—axil	Purple	Green	3 : 1	Rangaswami Ayyangar *et al.* [1940]

Pgt—pgt	Seed	Purple tip	No purple tip	3 : 1	Rangaswami Ayyangar *et al*, [1938]
Ph—ph	Glume	Purple hairs	Hyaline hairs	3 : 1	Rangswami Ayyangar and Reddy [1940]
Pj—pj	Leaf—junction and nodal band	Purple	Green	3 : 1	Rangaswami Ayyangar [1940]
Pls—pls	Seedling late stage	Ditto	Ditto	3 : 1	Rangaswami Ayyangar *et al.* [1938]
Ps—ps	Stigma	Ditto	No purple	3 : 1	Rangaswami Ayyangar [1939]
Pw—pw	Spikelets pedicelled	Purple wash	Green	3 : 1	Rangaswami Ayyangar and Ponnaiya [1938]
Px—px	Panicle	Purple pulvinus	No purple	3 : 1	Rangaswami Ayyangar and Nambiar [1941]
Py—py	Glume	Coriaceous top nerved	Papery – full nerved	3 : 1	Rangaswami Ayyangar and Rao [1936] Rangaswami Ayyangar [1939]
Q—q	Leaf—sheath and glume (mature)	Reddish purple	Blackish purple	3 : 1	Rangaswami Ayyangar *et al.* [1933]
R—r	Coleoptile	Red	Green	3 : 1	Reed [1930], Karper and Conner [1930]; Martin [1935]; Rangaswami Ayyangar [1930]
R—r	Dry anther and seed pericarp	Red	No red	3 : 1	Graham [1916]; Rangaswami Ayyangar *et al.* [1933]; Sieglinger [1933]
R—r	Disease resistance	Smut resistance	Susceptibility (milo)	3 : 1	Reed [1930]; Marcy [1937]
Rs—rs	Stem	Red	Green	3 : 1	Stephens and Quinby [1939]
S—s	Seed	Thick mesocarp (spreader)	Thin mesocarp	3 : 1	Sieglinger [1924]
S—s	Disease resistance	Smut susceptibility	Resistance	3 : 1	Marcy [1937]
Sb—sb	Stigma	Feathers bushy	Sparse	3 : 1	Rangaswami Ayyangar and Nambiar [1939]
Sc—Sc	Seed	Not scented	Scented	3 : 1	Rangaswami Ayyangar [1939]
Sh—sh	Spikelets sessile	Non-shedding	Shedding	3 : 1	Rangaswami Ayyangar *et al.* [1936]
Sh_1—sh_1	Spikelets pedicelled	Persistent	Deciduous	3 : 1	Rangaswami Ayyangar *et al.* [1937]
So—so	Habit	Spreading	Erect	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Stbf—stbf	Stigma	Fully feathered	Basal feathered	3 : 1	Rangaswami Ayyangar and Reddy [1938]
Su—su	Seed—endosperm	Starchy	Sugary	3 : 1	Karper [1933]; Martin [1936]
T—t	Plant height	Tall	Normal kafir	3 : 1	Karper [1932]
Ts—ts	Seed	Double (twin)	Single	3 : 1	Rangaswami Ayyangar and Rao [1936]; Karper and Stephens [1936]; Stephens and Quinby [1938]; Rangaswamy Ayyangar [1939]
Tu—tu	Habit	Delayed tillering	Uniform tillering	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]

* Old genic symbols with all capital letters have now been changed to first letter capital and the rest small

APPENDIX II—*contd.*

Symbols 1	Plant part 2	Characters: Dominant 3	Characters: Recessive 4	Ratio 5	Authority and date published or reported 6
Tx—tx	Habit	Tillering	Single stalked	3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
U—u	Seed shape	Umbonate	Round top	3 : 1	Rangaswami Ayyangar *et al.* [1935]
V_1 & V_2—v_1 & v_2	Seedling—chlorophyll	Normal green	Virescent white	3 : 1	Karper and Connor [1930] ; Martin [1936]
V_3 to V_8—v_3 to v_8	Ditto	Ditto	Ditto	3 : 1	Quinby and Karper [1934] ; Martin [1936]
W—w	Seed-pericarp colour	Whole coloured	Base only coloured	3 : 1	Rangaswami Ayyangar *et al.* [1933]
W_1 to W_4—w_1 to w_4	Seedling—chlorophyll	Normal green	White	3 : 1	Karper and Conner [1930] ; Martin [1936]
W_5 to W_{12}—w_5 to w_{12}	Ditto	Ditto	Ditto	3 : 1	Quinby and Karper [1934] ; Martin [1936]
Wx—wx	Seed—endosperm	Starchy	Waxy	3 : 1	Karper [1933] ; Martin [1936]
Wy—wy	Peduncle	Straight	Wavy	3 : 1	Rangaswami Ayyangar [1939] ; Rangaswami Ayyangar and Ponnaiya [1941]
X—x	Stalk	Insipid	Sweet	3 : 1	Rangaswami Ayyangar *et al.* [1936]
Y—y	Seed—pericarp colour	Yellow	No yellow (white)	3 : 1	Graham [1916]
Y_1—y_1	Leaf	Normal	Yellow	3 : 1	Quinby and Karper [1934] ; Martin [1936]
Y_1 to Y_4—y_1 to y_4	Seedling—chlorophyll	Normal green	Ditto	3 : 1	Karper and Conner [1930] ; Martin [1936]
Y_5 & Y_6—y_5 & y_6	Ditto	Ditto	Ditto	3 : 1	Quinby and Karper [1934] ; Martin [1936]
Ymd—ymd	Leaf—midrib	Yellow	Non-yellow	3 : 1	Martin [1931] ; Martin [1936] Rangaswami Ayyangar and Ayyar [1940]
Yx—yx	Seedling—chlorophyll	Normal green	Xantha	3 : 1	Rangaswami Ayyangar and Reddy [1937]
Z—z	Seed	Thin mesocarp (pearly)	Thick mesocarp (chalky)	3 : 1	Rangaswami Ayyangar *et al.* [1934]
Z—z	Leaf	Normal	Zebra	3 : 1	Quinby and Parker [1934] ; Martin [1936]

APPENDIX II—*contd.*

C. Characters for which no genic symbols have yet been given

Plant part	Character		Ratio	Authority and date published or reported
	Dominant	Recessive		
Seedling— Stem	Red	Green	9 : 7	Woodworth [1936]
Chlorophyll	Normal green	White (lethal)	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Virescent white (lethal)	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Pale green (lethal)	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Pale green (lingering)	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Pale green (surviving)	3 : 1	Rangaswami Ayyangar and Ayyar [1932]
Ditto	Ditto	Patchy pale	3 : 1	Rangaswami Ayyangar [1939]
Leaf— Tip	Non-drying	Drying	3 : 1	Rangaswami Ayyangar [1939]
Axil	Purple	Green	9 : 7	Rangaswami Ayyangar [1939]
Stalk— Mechanical tissue	Colourless	Brownish yellow	9 : 7	Rangaswami Ayyangar [1939]
Thickness	Normal (kafir)	Tenuous	3 : 1	Sieglinger [1929]
Panicle— Shape	Loose	Compact	3 : 1	Ramanathan [1924]; Parker [1927]; Martin [1936]; Rangaswami Ayyangar [1934]
Ditto	Acicular spindle	Oval	3 : 1	Rangaswami Ayyangar [1939]
Ditto	Medium compact	Compact	3 : 1	Rangaswami Ayyangar [1939]
Branches	Short	Long	3 : 1	Karper [1931]; Martin [1936]

APPENDIX II—*contd.*

Plant part	Character		Ratio	Authority and date published or reported
	Dominant	Recessive		
Panicle—				
Rachis	Shoit	Long	3 : 1	Karper [1931] ; Martin [1936]
Nodes	Few	Many	3 : 1	Karper [1931] ; Martin [1936]
Shoots from axils	Normal	Shoots from axils of branches	3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
Spikelets (sessile)	Small ovate with short awn	Big elliptic with long awn	3 : 1	Rangaswami Ayyangar and Reddy [1940]
Ditto	Normal	Bulbils	3 : 1	Rangaswami Ayyangar [1939]
Glumes	Green at anthesis	Purple at anthesis	3 : 1	Rangaswami Ayyangar and Reddy [1940]
Ditto	Both glumes coriaceous	Papery lower glume and coriaceous upper glume	3 : 1	Rangaswami Ayyangar [1939]
Ditto	Ditto	Thinly crustaceous	3 : 1	Rangaswami Ayyangar [1939-40]
Ditto	Short	Long	3 : 1	Graham [1916]
Ditto	Broad	Narrow	3 : 1	Vinall and Cron [1921] ; Rangaswami Ayyangar [1934]
Ditto	Wrinkled	Smooth	3 : 1	Ramanathan [1924]
Ditto	Wrinkled (both)	Not wrinkled (both)	9 : 7	Rangaswami Ayyangar [1939]
Ditto	Ditto	Upper only wrinkled	3 : 1	Rangaswami Ayyangar *et al.* [1942]
Glumes—tip	Red	No red	3 : 1	Ramanathan [1924]
Anther (fresh)	Yellow	Light purple wash	3 : 1	Rangaswami Ayyangar [1939-40]
Endosperm	Starchy	Waxy	15 : 1	Rangaswami Ayyangar [1939]
Plant height	Normal kafir	Double dwarf	3 : 1	Sieglinger [1933]

Disease resistance—				
Red spot . . .	Susceptibility . . .	Resistance . . .	3 : 1	Swanson and Parker [1932]; Martin [1936]
Root rot . . .	Ditto . . .	Ditto . . .	3 : 1	Bowman *et al.* [1934]; Martin [1936]

APPENDIX II—*contd.*

D. Characters inherited independently

Characters	Symbols	Ratio	Authority
White seedlings and yellow seedlings	W^1, Y^3	9 : 3 : 4	Karper [1933] ; Martin [1936]
Ditto	W^2, Y^1	9 : 7	Karper [1933] ; Martin [1936]
Ditto	W^2, Y^3	9 : 7	Karper [1933] ; Martin [1936]
White seedlings and red coleoptile	W^1, R	9 : 7	Karper [1932] ; Martin [1936]
Ditto	W^2, R	9 : 7	Karper [1932] ; Martin [1936]
White seedlings and waxy endosperm	W^1, Wx	9 : 3 : 3 : 1	Karper [1933] ; Martin [1936]
White seedlings and sugary endosperm	W^1, Su	9 : 3 : 3 : 1	Karper [1934] ; Martin [1936]
Ditto	W^2, Su	9 : 3 : 3 : 1	Karper [1934] ; Martin [1936]
Virescent seedlings and waxy endosperm	V^1, Wx	9 : 3 : 3 : 1	Karper [1933] ; Martin [1936]
Ditto	V^2, Wx	9 : 3 : 3 : 1	Karper [1933] ; Martin [1936]
Virescent seedlings and sugary endosperm	V^1, Su	9 : 3 : 3 : 1	Karper [1934] ; Martin [1936]
Virescent seedlings and yellow seedlings	V^2, Y^3	9 : 6 : 1	Karper [1933] ; Martin [1936]
Virescent yellow and nucellar layer	V^2, B	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Yellow seedlings and yellow seedlings	Y^1, Y^2	9 : 7	Karper [1932] ; Martin [1936]
Ditto	Y^2, Y^3	9 : 7	Karper [1932] ; Martin [1936]
Yellow seedlings and red coleoptile	Y^1, R	9 : 3 : 3 : 1	Karper [1933] ; Martin [1936]
Ditto	Y^2, R	9 : 3 : 3 : 1	Karper [1933] ; Martin [1936]

Yellow seedlings and waxy endosperm	**Y^1, Wx**	9 : 3 : 3 : 1	Karper [1933] ; Martin [1936]
Ditto	**Y^3, Wx**	9 : 3 : 3 : 1	Karper [1933] ; Martin [1936]
Red coleoptile and waxy endosperm	**R, Wx**	9 : 3 : 3 : 1	Karper [1933] ; Martin [1936]
Ditto	**Rs, Wx**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Red coleoptile and nucellar layer	**R, B**	..	Stephens and Quinby [1930] ; Martin [1936]
Red coleoptile and spreader	**Rs, S**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Red coleoptile and awn	**Rs, A**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Seedlings—			
Stem colour and plant colour (red—black)	**Rs, Q**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Stem colour and nucellar layer	**Rs, B**	9 : 3 : 3 : 1	Stephens and Quinby]1938]
Stem colour and green striped	**Rs, Gs**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Stem colour and grain pericarp colour (coloured white)	**Rs, R (W?)**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Stem colour and male sterile	**Rs, Ms**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Colour (bluish green) and midrib rigidity	**Cbl, Md**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Yellow leaves and stems and glume colour (dominant red)	**Cy, Gb**	..	Stephens and Quinby [1933] ; Martin [1936]
Yellow leaves and midrib colour	**Cy, M**	..	Stephens and Quinby [1933] ; Martin [1936]
Yellow leaves and nucellar layer	**Cy, B**	..	Stephens and Quinby [1933] ; Martin [1936]
Golden leaves and nucellar layer	**Cg, B**	..	Stephens and Quinby [1931] ; Martin [1936]
Golden leaves and awns	**Cg, A**	..	Stephens and Quinby [1933] ; Martin [1936]
Golden leaves and glume colour (dominant black)	**Cg, Gr**	..	Stephens and Quinby [1933] ; Martin [1936]
Golden leaves and pericarp colour	**Cg, Pr**	..	Stephens and Quinby [1933] ; Martin [1936]

APPENDIX II—*contd.*

Characters	Symbols	Ratio	Authority
Red leaves and stems and midrib colour	**Cr, M**	9 : 3 : 3 : 1	Stephens and Quinby [1932] ; Martin [1936]
Red leaves and stems and nucellar layer	**Cr, B**	9 : 3 : 3 : 1	Stephens and Quinby [1932] ; Martin [1936]
Red leaves and stems and awns	**Cr, A**	9 : 3 : 3 : 1	Stephens and Quinby [1931] ; Martin [1936]
Red leaves and stems and spreader	**Cr, S**	9 : 3 : 3 : 1	Stephens and Quinby [1932] ; Martin [1936]
Red leaves and stems and glume colour (dominant black)	**Cr, Gr**	9 : 3 : 3 : 1	Stephens and Quinby [1932] ; Martin [1936]
Green striped and juiciness of stalks	**Gs, D**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Green striped and antherless	**Gs, Al**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Leaf-tip hairiness and node hairiness	**Lh, Nh**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1939]
Leaf tip hairiness and plant colour (sheath and glume) purple	**Lh, P**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1939]
Leaf tip hairiness and pericarp whole colour	**Lh, W**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1939]
Leaf-margin waviness and pericarp whole colour	**Mu, W**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]
Leaf-margin waviness and leaf-margin drying	**Mu, Md**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]
Leaf-margin waviness and bloom density	**Mu, H**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1937]
Leaf-margin drying and leaf junction corrugation	**Md, Jc**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]

Leaf-margin drying and pericarp colour intensification	**Md, I**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]
Leaf-margin drying and pericarp colour red	**Md, R**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]
Midrib colour and glume colour (dominant black)	**M, Gr**	9 : 3 : 3 : 1	Stephens and Quinby [1933] ; Martin [1936]
Midrib colour and glume colour (black-straw)	**M, Gs**	9 : 3 : 3 : 1	Stephens and Quinby [1931] ; Martin [1936]
Midrib colour and glume colour (dominant red)	**M, Gb**	9 : 3 : 3 : 1	Stephens and Quinby [1933] ; Martin [1936]
Midrib colour and pericarp colour . .	**M, Pr**	9 : 3 : 3 : 1	Stephens and Quinby [1933] ; Martin [1936]
Midrib colour and spreader . . .	**M, S**	9 : 3 : 3 : 1	Stephens and Quinby [1931] ; Martin [1936]
Midrib colour and nucellus . . .	**M, B**	9 : 3 : 3 : 1	Stephens and Quinby [1930] ; Martin [1936]
Midrib colour and awn	**M, A**	..	Stephens and Quinby [1930] ; Martin [1936]
Midrib colour yellow and juiciness . .	**Ymd, D**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Ayyar [1940]
Midrib hairy and juiciness . . .	**Mdh, D**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Leaf-junction corrugation and pericarp colour	**Jc, W**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]
Node hairiness and plant colour purple .	**Nh, P**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1939]
Node hairiness and hairy styles . . .	**Nh, Bc**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1940]
Node hairiness and pericarp colour (whole colour)	**Nh, W**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1939]
Node hairiness and awn (awnless and awned)	**Nh, A**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1939]
Plant colour purple (sheath and glume) and bloom density	**P, H**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1937]
Plant colour purple and awn (awnless—awned)	**P, A**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1939] ; Stephens and Quinby [1939]

APPENDIX II—*contd.*

Characters	Symbols	Ratio	Authority
Plant colour purple and antherless . .	**P, Al**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Plant colour purple and male sterile . .	**P, Ms**	9 : 3 : 3 : 1	Stephens aud Quinby [1939]
Plant colour purple (sheath) and basal feathered stigma	**P,** St_{bf}	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1938]
Plant colour purple (sheath) and waxy endosperm	**P, Wx**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Plant colour (red-black) and bloom density .	**Q, H**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1937]
Plant colour (red-black) and juiciness . .	**Q, D**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Plant colour (red-black) and awn . .	**Q, A**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Plant colour (red-black) and purple anthers .	**Q, Pan**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1938]
Plant colour (red-black) and stigma feathers	**Q,** St_{bf}	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1938]
Plant colour (red-black) and hairy styles .	**Q, Bc**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1940]
Plant colour (red-black) and glume purple at emergence	**Q, Gep**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Ponnaiya [1937]
Plant colour (red-black) and glume colour dilution	**Q, Cd**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Ponnaiya [1941]
Plant colour (red-black) and pericarp colour (red)	**Q, R**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Plant colour (red-black) and spreader .	**Q, S**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Plant colour (red-black) and waxy endosperm	**Q, Wx**	9 : 3 : 3 : 1	Stephens and Quinby [1938]

Bloom density and grain pericarp pearly chalky	**H, Z**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1937]
Bloom density and grain pericarp brown	**H, B**[1] (or **B**[2])	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1937]
Juiciness of stalk and taste of juice	**D, X**	9 : 3 : 3 : 1	Rangaswami Ayyangar [1934]
Juiciness of stalk and brownish purple stalks	**D, Mtb**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Nambiar [1937]
Juiciness of stalk and awn (awnless and awned)	**D, A**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Juiciness of stalk and male sterile	**D, Ms**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Juiciness of stalk and antherless	**D, Al**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Juiciness of stalk and pericarp colour	**D, R**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Juiciness of stalk and spreader	**D, S**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Juiciness of stalk and nucellar layer	**D, B**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Juiciness of stalk and waxy endosperm	**D, Wx**	9 : 3 : 3 : 1	Stephens and Quinby [1939]
Juiciness of stalk and plant height and duration	**D, In_1**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1937]
Juiciness of stalk and smut resistance	**D, K**	9 : 3 : 3 : 1	Swanson and Parker [1931]
Juiciness of stalk and pulvinus purple	**D, Px**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Nambiar [1941]
Glume size (short-long) and pericarp (red-white)	..	9 : 3 : 3 : 1	Graham [1916]
Glume texture (papery) and rolling in of the edges	**Py, Gx**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Ponnaiya [1939]
Glume colour (dominant black) and pericarp colour	**Gr, Pr**	..	Stephens and Quinby [1929] ; Martin [1936]

APPENDIX II—*contd.*

Characters	Symbols	Ratio	Authority
Glume colour (dominant black) and spreader	**Gr, S**	. .	Stephens and Quinby [1929] ; Martin [1936]
Glume colour (dominant black) and awn	**Gr, A**	. .	Stephens and Quinby [1933] ; Martin [1936]
Glume colour (dominant red) and awn	**Gb, A**	. .	Stephens and Quinby [1933] ; Martin [1936]
Glume colour (dominant red) and pericarp colour	**Gb, Pr**	.	Stephens and Quinby [1933] ; Martin [1936]
Glume colour (dominant red) and spreader	**Gb, S**	.	Stephens and Quinby [1933] ; Martin [1936]
Glume colour (black-straw) and awn	**Gs, A**	. .	Stephens and Quinby [1931] ; Martin [1936]
Felty glume and hairy style	**Gf, Bc**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1940]
Awn (awnless and awned) and length of style and stigma	. .	12 : 3 : 1	Rangaswami Ayyangar and Rao [1935]
Awn (awnless and awned) and spreader	**A, S**	9 : 3 : 3 : 1	Stephens and Quinby [1930] ; Martin [1936]
Awn (awnless and awned) and pericarp colour	**A, Pr**	9 : 3 : 3 : 1	Stephens and Quinby [1931] ; Martin [1936]
Awn (awnless and awned) and pericarp colour (coloured and white)	**A, W**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1939]
Awn (awnless and awned) and nucellar layer	**A, B**	9 : 3 : 3 : 1	Stephens and Quinby [1930] ; Martin [1936] ; Sieglinger [1934]
Awn-purple subule and pericarp colour red	**Ap, R**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]
Awn-purple subule and pericarp colour intensification	**Ap, I**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]
Antherless and nucellar layer	**Al, B**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Anthers purple and pericarp brown	**Pan, B_1 (or B_2)**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1938]
Anthers purple and nucellar layer	**Pan, B**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]

[illegible]	[illegible]	9 : 3 : 3 : 1	Rangaswami Ayyangar and Reddy [1940]
Twin seeds and nucellar layer	**Ts, B**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Twin seeds (extra fertile) and connate double seeds	**Ts, Co**	9 : 3 : 3 : 1	Rangaswami Ayyangar [1940]
Pericarp colour and grain shape	**W, U**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1935]
Pericarp colour and wash on pericarp	**W, M**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Nambiar [1938]
Pericarp red and pericarp pearly-chalky	**R, Z**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1934]
Pericarp red and wash on pericarp	**R, M**	9 : 3 : 3 : 1	Rangaswami Ayyangar and Nambiar [1938]
Pericarp red and pericarp brown	**R, B**	9 : 3 : 3 : 1	Vinall and Cron [1921]
Pericarp red and nucellar layer	**Pr, B**	9 : 3 : 3 : 1	Swanson [1928]; Martin [1936]; Stephens and Quinby [1931]; Sieglinger [1933]; Martin [1936]
	R, B	12 : 3 : 1 9 : 3 : 3 : 1	Stephens and Quinby [1938]
Pericarp red and spreader	**R, S**	15 : 1	Swanson [1928]
Pericarp colour and spreader	**Pr, S**	12 : 3 : 1	Stephens and Quinby [1933]; Martin [1936]
Pericarp brown and white	**B, S**	9 : 7	Vinall and Cron [1921]; Swanson [1928]
Nucellar layer and waxy endosperm	**B, Wx**	9 : 3 : 3 : 1	Stephens and Quinby [1938]
Nucellar layer and spreader	**B, S**	9 : 3 : 4	Stephens and Quinby [1930]; Martin [1936]; Sieglinger [1924]; Martin [1936]
Grain—blotching and purple tip	**Pb, Pgt**	9 : 3 : 3 : 1	Rangaswami Ayyangar *et al.* [1939]
Waxy endosperm and sugary endosperm	**Wx, Su**	9 : 3 : 3 : 1	Karper [1934]; Martin [1936]
Plant height — standard and dwarfs (broom corn)	**A, D**	9 : 3 : 3 : 1	Sieglinger [1932]
Standard and double dwarf	**D^1, D^2**	9 : 3 : 3 : 1	Karper [1934]; Martin [1936]

APPENDIX II—*concld.*

E. Linked characters

Characters	Symbols	Percentage of crossing over	Authority
Nucellar layer in grain and glume colour	**b, Gr**	25	Stephens and Quinby [1929]; Martin [1936]
Ditto	**b, Gb**	21	Stephens and Quinby [1929]; Martin [1936]
Ditto	**B, gb**	4·5	Stephens and Quinby [1931]; Martin [1936]
Nucellar layer in grain and green striped plants	**B, Gs**	12	Stephens and Quinby [1938]
Nucellar layer in grain and glume colour	**B, Q**	16	Stephens and Quinby [1938]
Brown wash on grain and sheath and glume colour	**B^1, Q**	Nil	Rangaswami Ayyangar *et al.* [1934]
Grain pericarp brown and pearly-chalky	**B^1, Z**	30	Rangaswami Ayyangar [1939]
Panicle shape and grain pearly-chalky	**Pa_1, Z**	1·07	Rangaswami Ayyangar and Ayyar [1938]
Midrib yellow and sheath and glume colour	**Ymd, Q**	35·5	Rangaswami Ayyangar and Ayyar [1940]
Leaf-tip hairiness and awn (nil—long)	**Lh, A**	43	Rangaswami Ayyangar and Reddy [1939]
Leaf-tip hairiness and stigma feathers—basal	**Lh, Stbf**	25	Rangaswami Ayyangar and Reddy [1939]
Awn (nil—long) and stigma feathers—basal	**A, Stbf**	18	Rangaswami Ayyangar and Reddy [1939]
Red coleoptile and midrib colour	**R, m**	21·5	Stephens and Quinby [1930]; Martin [1936]
Seedling stem colour and juiciness of stalk	**Rs, D**	10·9	Stephens and Quinby [1939]
White seedlings and red coleoptile	**W_3, R**	41·34	Karper [1930]; Martin [1936]
Plant colour purple and juiciness of stalk	**P, D**	30	Rangaswami Ayyangar *et al.* [1937]

Plant colour purple and seedling stem colour	**P, Rs**	16·4	Stephens and Quinby [1939]
Plant colour purple and coleoptile purple .	**P, Pc**	18	Rangaswami Ayyangar [1939]
Coleoptile purple and grain pericarp brown .	**Pc, B^2**	5	Rangaswami Ayyangar [1939]
Crustaceous glume and juiciness of stalk .		17	Rangaswami Ayyangar [1940]
Yellow seedlings and waxy endosperm .	**Y^2, Wx**	26·5	Karper [1930] ; Martin [1936]
E-ligulate leaves and axillary shoots in panicle		0·01	Rangaswami Ayyangar and Ponnaiya [1941]
Yellow leaves and stems and pericarp colour	**Cy, Pr**	13	Stephens and Quinby [1933] ; Martin [1936]
Pale green seedlings (lethal) and zygotic lethal		23·5	Rangaswami Ayyangar and Ayyar [1932]

INSECT PESTS OF STORED GRAINS IN THE PUNJAB AND THEIR CONTROL

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(With Plates XXIII and XXIV and 9 text-figures)

INTRODUCTION

CEREALS, millets, gram, pulses and other food grains are of vital importance to mankind. Under the abnormal stress of the prevailing tumultuous conditions, there is at present an unprecedented demand for them, which is bound to increase manifold with the passage of time. In order to meet the increasing demand, a Food Production Conference was held in Delhi on 6 April 1942, to consider ways and means of increasing the production of food grains in India. A similar Conference was also held at Lahore on 15 April 1942, to intensify efforts to increase the surplus produce in the Punjab* to the utmost extent possible.

Researches on food crops have resulted in the evolution of varieties which give an increased outturn of greatly improved grain and one of the recommendations made to the provincial Governments, by the Delhi Food Production Conference is, as reported in the press, to make arrangements to ensure the availability of adequate supplies of seed of improved varieties of food crops.

The success of this 'grow more food campaign' will inevitably lead to the increase of the insects which destroy grain in storage ; for a greater output of food grains will result in a larger surplus to be stored and the insects are notorious for accelerating multiplication and damage when there is an abundance of food material. Therefore, measures for the protection of food grains in storage against the depredations of insect pests must go hand in hand with the drive for more food production.

The actual damage caused by these insects to grain in storage is, owing to the absence of reliable data, extremely difficult to estimate precisely. In the Report on the Marketing of Wheat in India (published in 1937) it is stated that exporting firms assess the loss (to wheat) from weevil at about 2½† per cent. Mr T. B. Bainbrigge Fletcher, the late Imperial Entomologist, Pusa, in his article 'Weevil and dry wheat' (published in the *Agricultural Journal of India*, Vol. 6, 1911) has placed the weevil damage to wheat at 33 per cent. Such figures for the loss caused by the insect pests to rice, gram, maize and pulses are not available but, if 2½ per cent be taken as the standard

* The Punjab is a surplus province in the production of some of the food grains

† This is a very low estimate indeed because a loss of about 10 per cent caused by these insect pests to stored grains is not at all unusual

ate of loss for all these grains, the losses add up to a stupendous aggregate as will be seen from Tables I and II

TABLE I

Showing the quantity of stored grains annually destroyed by insect pests in India

Food grains	Total yield (in maunds)	Insect damage (in maunds) assessed at 2½ per cent	Money value (in rupees) of the grain (at harvest price)* damaged by insects
ice	629,076,000	15,726,900	30,470,869
Vheat	222,600,000	5,565,000	13,216,875
ram	76,188,000	1,904,700	4,761,750
arley	51,828,000	1,295,700	2,591,400
Iaize	49,560,000	1,239,000	2,710,312
Total	10,29,252,000	25,731,300	53,751,206

TABLE II

*howing the quantity of stored grains annually destroyed by insect pests in the Punjab***

Food grains	Total yield (in maunds)	Insect damage (in maunds) assessed at 2½ per cent	Money value (in rupees) of the grain (at harvest price)* damaged by insects
Vheat	90,580,000	2,264,500	5,378,188
ice	13,048,000	326,200	6,32,012
aize	10,752,000	268,800	588,000
ram	10,500,000	262,500	656,250
arley	4,228,000	105,700	211,400
Total	129,108,000	3,227,700	7,465,850

* Harvest prices in 1938-39
Wheat at Rs. 2-6 per maund
Gram at Rs. 2-8 per maund
Barley at Rs. 2 per maund
Rice at Rs. 1-15 per maund
Maize at Rs. 2-3 per maund

** Figures for the produce of the food grains for 1940-41 were available for the Punjab hile for India as a whole such figures were available only upto 1938-39. For the sake f uniformity, therefore, produce figures for 1938-39 are taken both for India and for the unjab

Thus, even at a most conservative estimate, India and the Punjab a respectively feeding about 25,731,300 and 3,227,700 maunds of food grai (valued at about Rs. 53,751,205 and Rs. 7,465,850) annually to insect pes Allowing $\frac{3}{4}$ seer of grain per adult man daily, it means that the insect pests stored grains in India and in the Punjab are depriving 40 lacs and five la of people respectively of food for 344 days in the year.

In India no serious effort appears to have been made so far to investiga ways and means of protecting from insect ravages food grains grown, harvest and stored with the sweat and toil of millions of tillers of the soil. Our kno ledge about these insects is so fragmentary that we do not even know all t insect pests of stored grains: Lefroy [1906] and Fletcher and Ghosh [191 found 15 and 18 different kinds of insects infesting various stored produ of which 8 and 13 were found injurious to stored food grains respectively. recent years as many as 36 different varieties of insects have been found in t Punjab infesting various stored products and of this lot no less than 19 insec damage food grains alone. I have reason to believe that still a numb of these pests remain to be discovered. In this article I have presented t information which has been collected in the Punjab mostly during the la $3\frac{1}{2}$ years about these pests with a view to stimulating interest in their stu as well as to acquainting those interested in their subjugation with the practical control. The economic importance of this problem together wi the exigencies of time demands that researches should be initiated imm diately to study these insects thoroughly in order to improve upon a enlarge the methods of combating them.

Insect pests

(i) *Khapra**

Identification. The adult** (Fig. 1) is a small dark-brown beetle with retractile head and clubbed antennae which are lodged in cavities on the unde side of the thorax. The male is smaller (it measures about 1/10 in. i length) and darker than the female.

Distribution. Though present throughout the plains of the Punjab, khap causes the greatest loss to wheat in the hotter and drier parts of the provin especially in the canal colonies.

Food. Khapra has been observed feeding on wheat, maize, *jow* (*Andropogon sorghum*), rice, barley, gram, pulses, *pista* (*Pistacia vera*), *khop* (*Cocos nucifera*) and walnut kernel, but it is really a serious pest of wheat.

Life-history. The pest passes the winter (October to March) in th larval stage in cracks and chinks of the walls and flour and other she tered places in a store. These larvae resume feeding in April. Adult beetle which are incapable of flight, appear during April to May when they cop late, the act of copulation lasting only for 1 to $1\frac{1}{2}$ minutes. One to thre

* *Trogoderma khapra* Arr: Dermestidae: Coleoptera

** The body of an insect is mapped out in three regions, namely, head, thorax a abdomen. Head carries eyes, antennae (or feelers) and the mouth parts, while the thora carries legs and wings; the abdomen, which is without such appendages, accommodat the organs of digestion, respiration and egg-production

days after mating, the females lay white translucent cylindrical eggs (generally) singly or (rarely) two to five together among the grain. Each female can lay upto 85 eggs in its life-time: these eggs are laid at the rate of 1 to 26 eggs per day in instalments within seven days. The eggs take three to five days to hatch in June and six to ten days in October. The newly hatched grub is yellowish-white in colour, but when full-grown (Fig. 2) it becomes brownish with numerous yellowish bands across its body which is very bristly and has a long tail of thick hairs. The grub can live without food for two to three years. Both adults and larvae avoid light [Rahman and Sohi. 1939] and are fond of resting against rough surfaces. The male larvae are full-fed in 19 to 28 days and the female in 20 to 37, when they measure about 1/6 in. in length. Pupation takes place in the last larval skin among the grains, the pupa being dark-brown in colour. The pupal stage lasts for four to six days. Male pupae are smaller than the female pupae.

FIG. 1. Khapra beetle

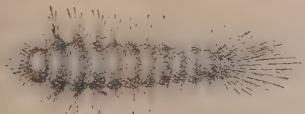


FIG. 2. Khapra grub

Damage. The adults are harmless, grubs alone being destructive. They are most active during July to September when they do the greatest damage. They abound in the top 10 to 12 in. of the wheat heap. They attack the grain at any point, more commonly at the embryo. The contents of the attacked grain are so completely destroyed that it is reduced to frass and waste flour.

(*ii*) *Susri**

Identification. The adult (Fig. 3) is a small, cylindrical beetle measuring 1/8 in. in length and 1/32 in. in breadth. It is dark-brown or black in colour with a deflexed head which is covered by a crenulate, hood-shaped pronotum. The antennae are ten-jointed and terminate in a prominent tripartite club.

Food. It is a most destructive pest of wheat, but it has also been observed doing considerable damage to rice, maize, *jowar*, barley and *singhara* (*Trapa bispinosa*) in the Punjab. Elsewhere it has also been found damaging lentils, biscuits, drugs, wheat ears, dried potatoes, corn flour, papers, beans, pumpkin seeds, tamarind seeds and millets.

FIG. 3. Susri beetle

Distribution. Susri is found all over the province but its areas of greatest destructiveness, as known at present, are Lyallpur, Amritsar, Gurdaspur, Jullundur and Palampur.

* The lesser grain borer: *Rhizopertha dominica* Fab: Bostrichidae: Coleoptera

Life-history. Susri hibernates both as a grub and as an adult during December to February. They resume activity in March and the adults, which are capable of fairly long flight, begin to lay eggs in April. A single female usually lays 300 to 400 eggs, in 23 to 60 days at the rate of 4 to 23 eggs per day. Pear-shaped eggs are laid either singly loose among the grain or they are laid in batches when they are glued to the grain. They are glistening-white when freshly laid but become rosy and opaque before hatching. They hatch out in five to six days in May to September and 11 to 26 days in October to November at 26° C. they hatch out in 12 to 18 days. The young larva bores into the grain which it passes its entire life. The larva undergoes four to five moults after which it pupates in the grain : at 26° C. it completes its larval stage in 52 days and its pupal stage in 6½ days. A full-grown grub (Fig. 4) is dirty-white in colour with a light-brown head and a constricted abdomen ; it measures 1/8 in. in length and lies curled up inside the grain. The adults rest for a few days inside the grain before appearing on the wing : they make irregular holes in the grains for emergence.

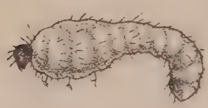


FIG. 4. Susri grub

Damage. The pest does the maximum damage during May to September. The adult is more harmful than the grub. The grubs eat out the starchy contents of the grain leaving behind the outer husk only. The adults destroy healthy grains which they reduce to frass and waste flour : they destroy far more than they can consume. The waste flour serves as food for the young grubs which feed on it until they bore into the grain.

(*iii*) *Sundwali susri**

Identification. The adult weevil (Fig. 5) is a cylindrical beetle which measures about 1/8 in. in length : it has a distinct snout which projects downwards from the head. It is brownish in colour with four light reddish-yellow spots on the wing-covers**. Its thorax has numerous round and shallow pits.

Food. In the Punjab sundwali susri is a very destructive pest of wheat, rice, maize, and *jowar*, but elsewhere it has also been reported damaging oats, barley, cotton seed, linseed and cacao.

Distribution. Though present throughout the province, sundwali susri is a serious pest in the mountainous (viz. Kangra and Kulu valleys and the Simla hills) and sub-montane (e.g. Gurdaspur, Sialkot, Ludhiana, Ambala) tracts of the province.

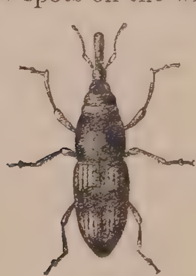


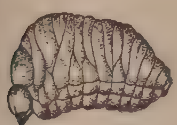
FIG. 5. Sundwali susri beetle

Life-history. The pest hibernates as adults in cracks and crevices and under gunny bags in stores. It starts breeding as soon as the weather warms

* The black weevil : *Sitophilus* (*Calandra*) *oryzae* Linne : Curculionidae Coleoptera

** In beetles and weevils the front wings are called wing-covers

p after winter. Females gnaw small holes in grains and lay one egg in each ole. A female can lay about 400 eggs in its life-time. The eggs, which re white in colour, hatch in six to seven days and the larva on hatching ores into the grain in which it feeds, grows and spends its entire larval life. he larvae are legless (Fig. 6) : they are full-grown in 15 to 30 days when ley are yellowish-white in colour and about 1/8 in. in length. They upate inside the grain, the pupal stage lasting for 6 to 14 days. The upa is at first dirty-white in colour, but later on it changes to dark-rown. Adults live for several months.



IG. 6. Grub of sundwali susri

Damage. The grubs eat out the starchy contents of the grain. The adults bite holes in the grain and ruin it : they are much more harmful than the grubs. It is the experience of the grain dealers that, while the attack of khapra is gradual and continuous, the attack of sundwali susri is sudden and irregular : it does considerable damage . a short time.

*v) The granary weevil**

This weevil does not appear to be so common in the Punjab as sundwali sri. Its adult resembles sundwali susri in appearance but is chestnut-own or black in colour and is without hind wings. Its life-history and the mage caused by it are identical with those of sundwali susri.

*) The grain moth***

Identification. The grain moth is a straw coloured, yellowish, small-zed insect with a wing expanse of ½ in. Its narrow hind wings are pointed at e end and are fringed with long hairs along their hind margins. It is an tive insect which, when disturbed, flies or crawls about actively, on or ear about the grain.

Food. It is a serious pest of wheat, maize and *jowar*. Elsewhere, it has en reported doing damage to barley, rye and oats also.

Distribution. In the Punjab, it has so far been found to be most harmful the Kulu valley, Palampur, Simla hills and the Ferozepur district.

Life-history. The pest winters-over as a caterpillar. It becomes active hen the weather warms up after winter. The adults mate immediately ter emergence. The females lay small eggs, which are white to begin with ut which become reddish before hatching, singly or in batches on or near e grain. A single female can, on an average, lay 150 eggs in its life-time and l these eggs are laid within a week after mating. The eggs hatch out in ur to eight days. The young larva burrows into a seed in which it spends s entire larval stage. A caterpillar is full-grown in about three weeks when measures 1/5 in. in length and is white in colour with a yellowish-brown ad. Before turning into pupa, the caterpillar eats out an emergence-tunnell aving a thin membrane of the seed coat as a lid for the exit hole and then

* *Sitophilus (Calandra) granaria* Linne : Curculionidae : Coleoptera

** *Sitotroga cerealella* Olivier : Gelechidae : Lepidoptera

it constructs a silken cocoon in the grain in which it turns into pupa. The pupa is reddish-brown in colour. The pupal stage occupies about ten days.

Damage. Caterpillars alone do damage. They generally abound in the upper layers of the stored grain. They do most of the damage during the monsoon rains—July to September. They bore into the grain, feed on its contents and fill the resultant cavity with their excreta : in severe cases of infestation, the attacked grain smells offensively. On many occasions the entire contents of the attacked grain are eaten but more usually one half of the grain is more completely hollowed out than the other.

(*vi*) *The rice moth**

Identification. The moth is of a uniform dark-grey colour. The females are slightly larger than males.

Distribution. It has so far been collected from Amritsar, Kala Shah Kaku and Lyallpur.

Life-history. Copulation generally takes place immediately after emergence and may last for as long as an hour and a quarter. Small, pearly-white eggs are glued singly to walls, bags and laid among food material ; they are usually deposited at night. They hatch in four to six days into creamy-white caterpillars which have a yellow head. When full-fed they construct an elongate, closely woven white cocoon in which they change into brownish pupae. The pupal stage lasts for 10 to 14 days.

Damage. It is a minor pest of rice which it destroys by eating. It also feeds on wheat bran.

(*vii*) *The red flour beetles***

Identification. The adult beetle is a small reddish-brown insect which measures about 1/6 in. in length. Its antennae are distinctly bent and terminate in a club which is formed by the last three joints.

Food. It feeds on rice, *jowar*, maize, wheat, gram, pulses, Quaker oats, wheat bran, biscuits : at Lyallpur it is commonly found in flour mills breeding in flour deposits in neglected places. Elsewhere, it has also been reported doing damage to beans, cotton seed, stale bread, cake, peanuts, ginger, mustard, groundnut, brown sugar, etc.

Distribution. The pest is almost uniformly distributed throughout the plains and sub-montane regions of the Punjab.

Life-history. The adults are active little creatures and can fly for a short duration : they, however, usually remain hidden in flour, grain heaps or under any other shelter. They hibernate during winter but become active during spring when they start breeding. After mating, females lay white, transparent, cylindrical eggs singly in flour or among grains : they may also be laid in cracks or on racks. Being sticky, they get covered with flour and dust and are, therefore, difficult to detect. A female can lay about 960 eggs in its life-time. The eggs hatch in four to ten days into tiny yellow-white grubs. The larval stage is completed in 22 to 25 days at 30° C. when the larva becomes reddish-yellow in colour and about 1/4 in. in length, its body being covered with hairs. These

* *Corcyra cephalonica* Staint : Pyralidae : Lepidoptera

** *Tribolium castaneum* Hbst : Tenebrionidae : Coleoptera

arvae, which shun light, are always found hidden in the food they infest They change into yellowish and hairy pupae in the flour or among grains. The pupal stage is completed in five to nine days. A generation is completed n 26 to 30 days in summer.

Damage. This insect does not feed on sound grain but on broken and lamaged grain which it destroys in considerable quantities. It is a very erious pest of flour and flour products which, when seriously infested, turn reyish, become mouldy, emit a pungent, disagreeable smell and become unfit or human consumption.

viii) Moong *dhora**

Identification. The adult is a small, oval, chocolate-coloured beetle hich measures about 1/6 in. in length : wing-covers of the female are ornaiented with a central trapezoidal black patch which is absent or very faint in he male.

Food. It is a major pest of *moong* (*Phaseolus mungo*). *moth* (*Phaseolus conitifolius*), *mash* (*Phaseolus radiatus*), *lobia* (*Phaseolus calcaratus*), peas and ow peas. Elsewhere, it has also been reported damaging pigeon peas, large hite beans (*Dolichos lablab*), gram and soy-beans.

Distribution. This insect was first noted in the Punjab in 1934. It as so far been collected from the following localities :—Ajnala, Banga, Gurdasur, Gurgaon, Jhang, Jullundur, Karnal, Lahore, Lyallpur, Multan, Palampur, anipat, Raiwind, Shergarh and Sheikhupura.

Life-history. Adults, which are strong and swift fliers, mate soon after nergence. Females glue their oval, whitish eggs singly or several of them ogether to a grain, any time within 72 hours of mating. A female can lay pto 150 eggs which she lays in 2 to 12 days at the rate of 1 to 82 per day. ggs hatch in three to six days in May to August, four to eight days in Septnber to October, 8 to 13 days in November and 18 days in December. he newly hatched larvae bore directly into the grain from the eggs. The itire larval life, which occupies 12 to 25 days in April, 8 to 31 days in ay to November and 26 to 43 days in December is passed inside the grain. ver-wintered larvae take 96 to 145 days to complete their development. he full-grown larva lies just beneath the seed-coat where it pupates. The ipal stage lasts for 8 to 23 days in March, 5 to 15 days in April to ctober and 12 to 36 days in November to December. It passes the winter Vovember to March) as a hibernating larva.

Damage. Only larvae do damage : they eat out the entire contents the grain leaving only the shell behind. The adult beetles escape by cutting it a circular hole in the shell. As generation after generation is passed in iick succession during the active season (March to October) and as only ie larva develops in a single grain, the entire quantity of stored pulses is duced to a mass of empty shells, each shell having a circular hole at one id. When pulses stored in an airtight receptacle are attacked, a fungus, hich gives out an offensive smell, develops in them.

* *Bruchus analis* Fab : Bruchidae : Coleoptera

(*ix*) *Dhora**

Identification. The adult (Fig. 8) is an oval, chocolate coloured beetle measuring 1/8 in. in length with long serrated antennae. The thorax is furnished with a pair of ivory-white elongated prominences in the middle of its hind margin. The wing-covers do not extend to the tip of the abdomen.

Food. It feeds on grams, peas, pigeon peas, cow peas, lentils and pulses but in the Punjab it is really a pest of gram.

Distribution. It has been collected from Banga, Gurgaon, Jhang, Karnal, Lyallpur, Multan, Panipat and Palampur.

Life-history. The pest hibernates during winter as larva. The adults begin to appear towards the end of March. Females glue their small, oval scale-like eggs (Fig. 7*a*) to the seed (Fig. 7*b*) in the top layer of a heap. A single female can lay up to 113 eggs. The eggs hatch in 7 to 14 days in April, 4 to 6 days in September, and 8 to 16 days in November. The larvae (Fig. 7*c*) have a curved H-shaped plate on the fore part of the thorax which they use as a lever when making a hole in the grain for getting in. The larval stage is completed in 17 to 33 days in April to May, 10 to 26 days in June to September and 14 to 38 days in October to November. Full-grown grubs migrate underneath the seed-coat where they turn into white and oval pupae (Fig. 7*d*). The pupal stage lasts for four to 13 days in May to August, six to 18 days in September to October and 15 to 28 days in November. The adult emerges by cutting out a circular hole in the seed-coat (Fig. 7*b*).

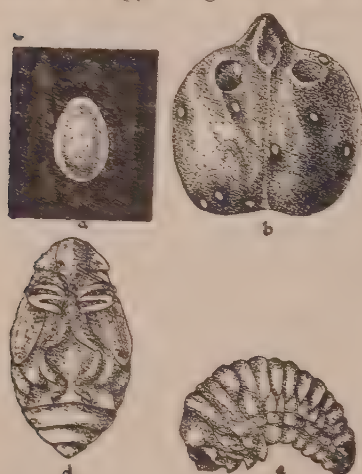


FIG. 7. Dhora (*a*) egg ; (*b*) damaged gram with eggs ; (*c*) grub ; (*d*) pupa ;

Damage. The adults do not take any food ; it is the grubs that do the damage. They are most destructive during April to September. They eat out the interior of the grain completely, leaving only the shell behind. Each attacked grain may have as many as eight larvae and one or more neat circular holes in it.

(*x*) *The saw-toothed grain beetle***

Identification. The adult is a slender, flattened, dark-red beetle about 1/10 in. long. The thorax bears two depressions on the back and six saw-tooth—like projections on each side.

Food. It feeds on wheat, rice, maize, *jowar*, dried dates, dried apricot, dried fig and almond. Elsewhere, it has been collected from barley, groundnut and oatmeal also.

* The cow pea weevil : *Bruchus chinensis* Linne : Bruchidae : Coleoptera

** *Oryzaephilus* (*Silvanus*) *surinamensis* (Linne) : Cucujidae : Coleoptera

Distribution. It is distributed throughout the Punjab.

Life-history. The adults, which live for more than five months, do not fly much. They lay eggs singly or in batches in or near the food. The egg is white when freshly laid but becomes yellowish before hatching. Each female can lay upto 85 eggs, which hatch in seven to nine days. The larvae are brown-headed, yellowish-white grubs whose bodies are clothed in numerous dark hairs. They move about actively in the foodmaterial infested by them. They are full-fed in about five weeks, when they pupate, the pupal stage occupying about a week. It completes its entire life-cycle in 35 days in May to July and 62 days in August to September.

Damage. It is a minor pest of stored grains, but a major pest of dried fruits which it damages by feeding and spoils by its excreta.

(*xi*) *The merchant grain beetle**

This insect, which has been found infesting wheat and dried fruits, is not so common in the Punjab as the saw-toothed grain beetle from which it differs in the possession of narrower and sharply projecting temples. Its life-history has not yet been worked out.

(*xii*) *The long-headed flour beetle***

Identification. This is a slender, flattened beetle of a shining pale-yellow colour which measures about 1/8 in. in length. Each of its wing-cover bears five lines of small punctures (or pits) on the upper side.

Food. It feeds on wheat, whetine and flour deposits in flour mills. Elsewhere, it has also been found infesting rice, corn, barley and rye.

Distribution. It has been collected from the following localities in the Punjab: Ferozepur, Jagraon, Jaranwala, Ludhiana, Lyallpur, Sangla Hill and Sargodha.

Life-history. It lays ovoid, opaque, smooth eggs in flour or on wheat grains. Young larvae show a remarkable resemblance with those of the red flour beetle, but when full-grown they can be distinguished by their lighter colour and narrower and smaller appendages on the 12th body joint. The larvae undergo six to nine moults. During the active period the pest completes its entire life-cycle in 25 to 39 days.

Damage. It is a minor pest of wheat and flour in the Punjab

(*xiii*) *Cadelle****

Identification. This is one of the biggest grain pests. Its adult is a dark-brown to black beetle, whose head and fore part of the thorax are joined to the rest of the body by a distinct joint. It measures about 1/3 in. in length.

Food. It feeds on rice and wheat. Elsewhere, it has been reported feeding on maize and oats also.

Distribution. This insect, which was first recorded in the Punjab in 1934, is widely distributed in the province.

Life-history. The pest passes the winter in the larval and adult stages. The adults live for more than two years. They lay their white eggs on or

* *Silvanus mercator* Fauv : Cucujidae : Coleoptera

** *Latheticus oryzae* Waterh : Tenebrionidae : Coleoptera

*** *Tenebroides mauritanicus* Linne : Ostomidae : Coleoptera

near their food. The full-grown larva is white in colour and has two short dark hooks at the end of its body : it measures 3/4 in. in length. The larva burrows into wood work for pupation.

Damage. It is a very minor past of wheat and rice in the Punjab. Elsewhere, in addition to feeding on different grains, it is said to prey upon other insects also.

(*xiv*) *The black fungus beetle**

This beetle which measures about 1/4 in. in length, is black or reddish-brown above and brown or rust-red below. It is generally met with in dark and damp places in wheat godowns where it probably feeds on moulds, etc. In the laboratory its adults were fed on khapra and red flour beetle larvae but in the absence of other food, they feed on wheat. A female lays a maximum of 56 eggs which hatch in about a week. The larvae are whitish-yellow with dark heads. The larval stage is completed in 7 to 24 days in July to October and pupal stage in 7 to 17 days in May to November.

This insect does not appear to be of any importance in the Punjab as a pest of stored grains.

(*xv*) *The flat grain beetle***

This is a flattened beetle of reddish-brown colour with long antennae and measures about 1/16 in. in length. It is a cosmopolitan insect and in the Punjab it has been collected from wheat and flour. Elsewhere, it has been collected from maize, rice, coffee, dates and biscuits. It is a minor pest in the Punjab and its life-history has not yet been worked out.

(*xvi*) *Thorictodes beetle****

This is probably the smallest of the stored grain insects in the Punjab. It was collected from wheat along with other pests from a mill at Lyallpur. Its status in relation to wheat is not yet known.

(*xvii*) *Miscellaneous pests*

Such insects as : (17) the black carpet beetle (*Attagenus piceus* Oliv.: Dermestidae : Coleoptera), (18) the tobacco beetle (*Lasioderma serricorne* Fab. : Anobiidae : Coleoptera) and (19) (*Kokeniella lineatopunctata* Kraatz : (Tenebrionidae : Coleoptera), have also been collected from wheat godowns but their true importance in relation to wheat remains to be ascertained.

Methods of storage

In the Punjab, the methods of storing grain depend upon (1) the tract in which it is stored, (2) the class of people storing it, (3) the variety of grain which is stored, and (4) the purpose for which it is stored. These methods are described below :—

(A) *Containers used by householders and small cultivators*

(*i*) *Earthen containers*. These containers, which are prepared by potters, are in universal use among the poorer classes throughout the province. They vary in shape and size. They are used for storing flour, pulses, *jowar*, rice and small quantities of oil-seeds meant for seed purposes, the quantity of the material stored in them varying from a few seers to about a maund.

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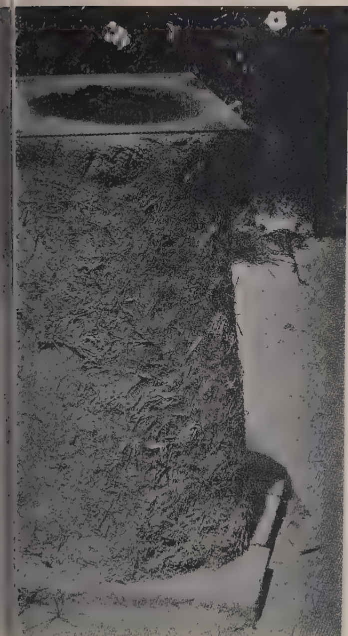
* *Alphitobius piceus* Oliv : Tenebrionidae : Coleoptera

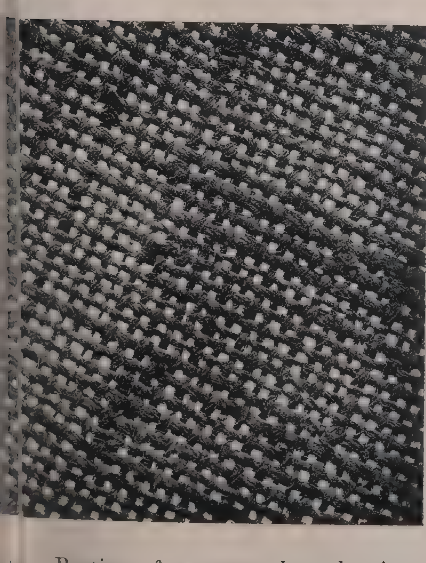
** *Laemophloeus pusillus* Schon : Cucujidae : Coleoptera

*** *Thorictodes heydeni* Rtt : Thorictidae : Coleoptera



1 'Bharoli' with glass lid

FIG. 2. Above-ground reinforced concrete bin



3. Portion of a gunny bag showing interstices between strands of fibre

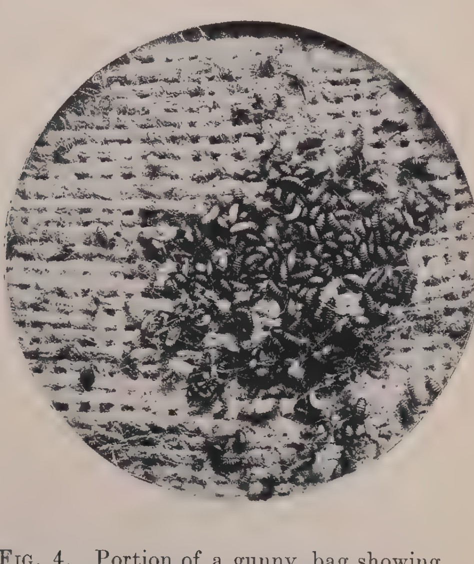


FIG. 4. Portion of a gunny bag showing khapra larvae clinging to it

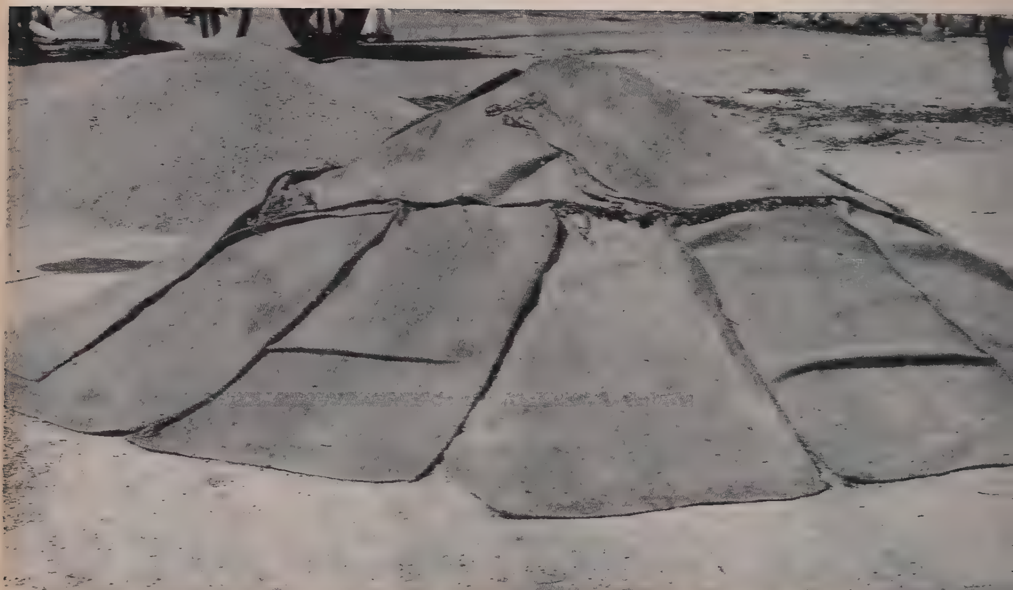


FIG. 1. Wheat heap covered with gunny bags

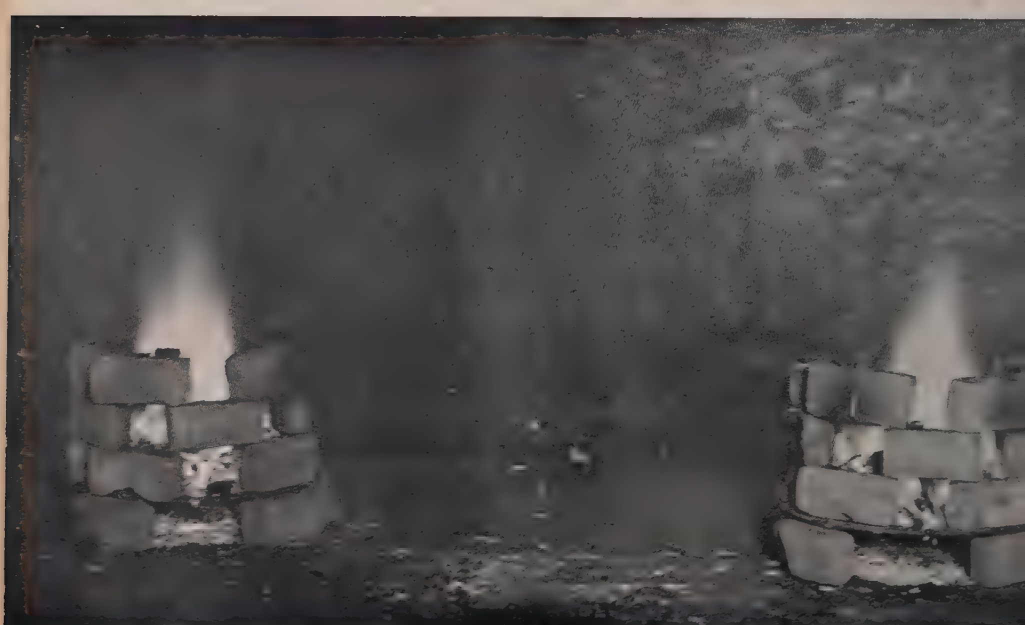


FIG. 2. Temporary furnace in action

(*ii*) *Earthen bins*. These bins have a variety of designs and forms: they may be (1) cylindrical, small ones being called 'bharoli' (Plate XXIII, fig. 1) and large ones being called 'bharola', (2) rectangular (called 'kothi'), or (3) square (called 'chauras'), in shape. They are made of clay mixed with 'bhusa';* the final structure being coated with a thin layer of cow-dung. These granaries are built on a platform inside the cultivators, residential quarters. They have an opening at the top (closeable with a lid) for putting in grain and a small side hole near the base for taking out the grain: 'kothis' are always supported on mud props and are generally without an opening on the top: they have an opening in the front wall big enough for a man to pass through it. These 'kothis' may be divided into compartments for storing different varieties of grain.

Earthen bins are used for storing wheat, rice and maize in bulk, the quantity stored in them varying from a small amount to 150 maunds, depending upon whether the grain is being stored for seed purposes or for household consumption. These bins are in common use in the districts of Ambala, Dera Ghazi Khan, Gujranwala, Hoshiarpur, Jullundur, Ludhiana, Muzaffargarh, Sialkot, but in the central districts and the Canal colonies they are mostly used by the poorer class of cultivators.

Grain stored in the earthen bins gets very badly attacked by insect pests of stored grains, damage by them being more pronounced and severe in the grain near the top opening and the side hole near the base.

(*iii*) *Bamboo bins*. These bins, which are locally known as 'pairoo', are prepared from matting of plaited thin strips of bamboo. They may be oval or cylindrical with an open top and a hole near the bottom and are placed, usually on a wooden support, inside the house, in a verandah, under an awning or under a shelter in the courtyard. The open top is closed with a lid which is plastered with mud. This method of storing grain is confined to the Kangra valley where it is employed by all classes of people for storing wheat, rice and maize. Normally they are of 10 to 15 maunds capacity but big cultivators get them made to hold 100 to 150 maunds of grain. Inspite of a plastering of a mixture of cowdung and mud over them, susri, sundwali susri and the grain moth easily get into these bins and cause serious damage to the grain stored in them.

(*iv*) '*Thekka*'. These are cylindrical structures which are made of strong, closely woven hemp cloth: sometimes a number of gunny bags are opened out and re-stitched to form one single large bag. These 'thekkas' are generally open at both ends. Their upper end may be secured to the roof or to some other support at a suitable height on the wall so that they hang perpendicularly and their lower end is placed over a circular platform of earth covered with a layer of sand or 'bhusa'. After 'thekka' is filled with grain its top is also finished off with another layer of sand or 'bhusa' the mouth being finally covered with a piece of hemp or a gunny cloth. These 'thekkas' are placed in any convenient part of the house and are commonly used in the Rohtak and Karnal districts.

* 'Bhusa' is broken straw and chaff produced during threshing

(*v*) '*Bukhari*'. This is an enclosure formed by fencing off a corner in the house by erecting two walls of wheat-straw, cotton sticks, *sarkanda* or of bricks and mud, perpendicular to the two walls enclosing the corner. Surplus grain, which is to be disposed of when prices are favourable or need for ready cash is pressing, is stored in this granary in bulk. This method of storage is rather common in the central districts of the Punjab.

(*vi*) *Baskets*. Sometimes maize cobs meant for seed are stored as such in baskets made from mulberry or bamboo sticks. The baskets are plastered with mud and are kept open on top without lids. *Jowar* heads also are sometimes stored in them.

(*vii*) *Iron pans*. Such pans when available with the cultivators, especially in the Lyallpur district, are also employed for storing grains.

(*viii*) *Wooden boxes*. Wooden boxes 5 ft. to 9 ft. long, 1 ft. to 1½ ft. wide and 2 ft. to 3 ft. high, made from *deodar* (*Cedrus labani* var. *deodara*) or *chil* (*Pinus longifolia*) wood are used for storing wheat, maize, and rice in the Kulu valley and the Simla hills.

Wooden boxes, baskets and iron pans do not constitute satisfactory containers from the point of view of insect damage.

(*ix*) *Miscellaneous methods of storage*. Grain may be stored in (1) wooden racks ('parchhatis') fitted in the wall of the house, (2) wooden chests or (3) in earthen pots placed one above another. In these containers only small quantities of grain are stored generally for a short time.

(B) *Containers used by big landlords, merchants and at Government farms*

(*i*) *Gunny bags*. These bags are made of jute fibre to contain 2½ maunds of wheat, rice or maize. They are used all over the province, but they are more commonly employed in the western districts, in most of the Canal colonies, especially among the urban population, in Mandi Baha-ud-Din, Rohtak, Hissar and Sonepat for storage of wheat. They are used for storing, in addition to wheat, gram, barley, rice, maize and oil-seeds. Bags filled with grain are piled up in godowns, open sheds, verandahs or even in the open as in the markets where during rains, etc. they are covered with tarpauline. As storage receptacles, they are unsatisfactory since they leave the grain exposed to the attack of insects from all sides which get in through the interstices (Plate XXIII, fig. 3) between the strands of fibre but due to the ease in the handling and transport of grain stored in them, they are very popular.

(*ii*) *Open heaps*. Grain is stored in bulk in a heap in any convenient and suitable enclosure (e.g. godown called 'kotha', or upper or lower storey of a two-storeyed building) which can give protection from the weather. This method of storing wheat is practised more commonly in the central and eastern Punjab markets. In recent years it has been taken up in Lyallpur and Okara markets also.

In some markets, e.g. Arifwala, special godowns are constructed with walls tarred to a height of 2 ft. to 3 ft. from the ground. Generally their walls and floors are pacca. In a few houses in Okara underground cellars have been provided for storing wheat.

Although the attack of insects is less in bulk storage than in bags, still the damage is considerable.

(*iii*) '*Palli*'. These containers are circular or conical in shape and are made from matting of plaited *sarkanda* or date-palm leaves. They may be

placed either on a raised mud platform or on logs of wood, bamboo or bricks and are fixed inside a house or, more generally, in the open. The bottom of the container is lined with ' bhusa ' and after it is filled with grain its top is also finished off with another layer of ' bhusa '. After filling in the grain its top opening is closed either with a plaster of mud or with a thatch lid which is fixed in position with mud. These ' pallis ' are commonly used for storing wheat, etc. in the districts of Multan, Muzaffargarh, Dera Ghazi Khan and Mianwali which receive an annual rainfall of not more than seven inches.

Wheat stored in these containers is said to remain free from insect pests.

(*iv*) ' *Kachha khatti*'. This method of storage is prevalent in Ambala and Karnal districts where large dealers and big zemindars adopt this system. ' Kachha khatti ' consists of an underground pit with a narrow opening at the top. Its walls and floor are plastered with mud and cowdung. After being filled with grain, its mouth is closed and plastered with mud, or with a thatch lid which is fixed with mud. These ' khattis ' can hold 200 to 300 maunds of grain. Although the grain in them is reported to suffer comparatively less from insect attack, considerable quantities of wheat at the bottom and along the walls get spoiled by moisture, turn black and thus become unfit for human consumption.

(*v*) *Metallic bins*. These bins are made of iron sheets and are built in a continuous series along the walls of a store-room with a path in between where their exit holes open. Each bin is fitted with a separate lid. These bins are commonly used at the Government agricultural farms in the Punjab. Their dimensions vary from 126 to 252 cubic ft. These bins, as constructed at present, are not insect-proof and the grain stored in them usually suffers considerable damage from insect pests. They have, however, one advantage over all other containers mentioned above : they can be made air-tight and fumigated efficiently and at a low cost whether empty or filled with grain.

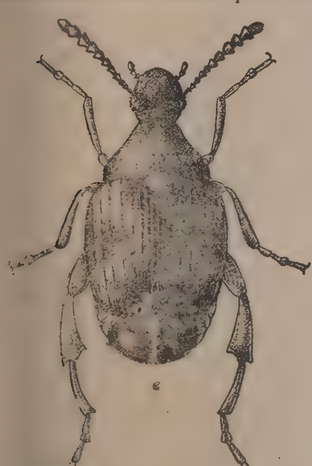


FIG. 8. Dhora (Adult)

(*vi*) *Reinforced concrete bins*. (Plate XXIII, fig. 2).* These bins are in use at the Lyallpur Agricultural Farm and in the Multan Central Jail, for storing wheat and gram. They are cylindrical, rectangular or hexagonal in shape and each is fitted with an exit hole near the bottom and a circular or square opening at the top which is closed with an iron lid. Their dimensions vary from 392 to 4405 cubic ft. As their lids do not fit tightly, insect pests of stored grains can easily get in them through the top opening and the exit holes. They have, however, the advantage that they can be easily

* At the Lyallpur Agricultural Farm, there is one such bin above ground and another below ground, each measuring 7 ft. × 7 ft. × 8 ft. The Deputy Director of Agriculture Lyallpur, informs me that, from the point of view of the cost of filling and emptying them as well as the storage of grain, the above-ground bin (Plate XXIII, fig. 2) is superior to the under-ground bin.

cleaned and disinfected before putting in grain and if during storage the gra gets infested, they can be easily and cheaply fumigated to kill the insect pes

Sources of infestation

Insect pests of stored grains do not develop from dust, dirt or grains spc taneously, but, like all other animals, they originate from an egg. The sto of the development of an insect is shown at Figs. 7 and 8. It will be se from these figures that there are four stages in the life-cycle of a beetle, wee or a moth-egg, larva, pupa and adult. The larva of a beetle and a weevil commonly known as a grub while that of a moth is called a caterpillar.

Infestation of sound and healthy grains by insect pests may originate frc the following sources :—

(*i*) Infestation may start in the field before the grain is harveste This is particularly true in the case of sundwali susri, dhora and the gra moth which lay eggs on wheat heads, gram pods and corn kernel respectivel in the fields. When such grains are brought in for storage, these pests ent the store-room as eggs. In the Punjab, however, these pests also exist stores and as soon as the grain is brought in they start breeding in it.

(*ii*) Insect pests already present in the store-room from year to ye constitute the major source of infestation. The grubs of khapra and adul of sundwali susri spend the winter season hiding in cracks, crevices ar chinks in the walls, floor and ceiling of the store-room and when fresh gra is brought in during summer they attack it.

(*iii*) Gunny bags used either for bringing in the grain from the threshi floor to the store or the bin, or for storing fresh grain, may often harbour large number of the stored grain pests in one stage of development or anoth These pests enter the store along with the grain and thus infest it.

(*iv*) Insect pests of stored grains are active and restless little creature Some of them, e.g. susri and dhora, are good fliers while others, e.g. sundwa susri, are sturdy and steady crawlers. Therefore, they travel by flyi or crawling from infested bins, warehouses, granaries and stores to uninfes ed ones and thus spread infestation.

(*v*) A clean store is often contaminated by infested grains brought fro mandies, etc. and stored in it.

(*vi*) Infested grains are very often taken out of the stores and sprea in the sun or winnowed. The stored grain pests from such stock fly or cra into the adjoining stores in the neighbourhood.

Parasites and predators

The stored grain pests have few natural enemies which do not appear t exercise any check on them. So far we have found only the following thr enemies of these pests in the Punjab :—

(*i*) *Bruchobius laticeps* Ashm. This is a larval parasite of dhora an *moong* dhora, which was first collected in 1934. It is fairly widely distr buted in the province and has so far been reported from Panipat, Karna Shergarh, Lahore and Jhang.

(*ii*) *Cephalonomia tarsalis* Ashm. This is the larval parasite of th saw-toothed grain beetle which was collected from larvæ infesting melon see kernel.

(*iii*) *Predaceous mite.* An unidentified mite of a pale colour has been found to feed upon the eggs of khapra.

Preventive and control measures against insect pests of stored grains

The problem of control of the insect pests of stored grains is a difficult and complex one and inspite of anxious and patient toil the results obtained are annoyingly slow. A few of the more important obstacles which an investigator engaged on this problem has to face and to surmount before he can hope to evolve effective methods of combating these pests are mentioned below :—

(*i*) The various grains are stored for human consumption or for seed purposes. Therefore, the poison to be used for keeping down insect pests should neither (like naphthalene) be absorbed by, nor adhere to, the grain ; it should also not affect (like sodium fluosilicate) their germination.

(*ii*) Illiteracy and poverty of the cultivators, and the absence of air-tight receptacles and godowns in the case of merchants and big landlords together with the general apathy and complete indifference of all hoarders of grain towards fumigants, make the use of such chemicals, which are very popular in other countries, a highly hazardous, unwelcome and difficult undertaking.

(*iii*) Different methods of storing grain are in vogue in different tracts of the province and with different classes of people. Control measures, irrespective of the kind of grain and the pest and its habits and behaviour, should fit in with these methods and people ; must be cheap and must not demand any extra attention and time for their application.

Preventive methods

'Prevention is better than cure' is an old adage which should be followed most rigidly by every one, big or small, who stores grain. By these methods damage by insects to grain is either minimized considerably or is prevented altogether. In the main these methods consist in keeping containers, granaries, godowns, mills, etc. clean by (*i*) thoroughly cleaning them before putting in the grain and immediately on its removal, (*ii*) the safe and regular disposal of all grain, seed and flour and other material in which these pests breed, and (*iii*) keeping screenings and other waste products (e.g. 'mumni', weed seeds, shrivelled grains) away from them. Attention must also be paid to the following points (*i*) bringing the grain straight from the threshing floor to the cleaned bins, (*ii*) thoroughly sun-drying the grain before storing and (*iii*) storing grain in a perfectly dry godown away from an infested godown, etc.

(*i*) *Improved earthen bin.* This bin has been evolved to prevent the infestation of grain once healthy grain has been stored in it.

The bin is cylindrical with a tapering bottom which is supported on a wooden tripod. There is about $1\frac{1}{2}$ in. to 2 in. wide and $1\frac{1}{2}$ in. deep groove round its top circular opening (Fig. 9). After the grain has been put in this bin, the groove is filled with powdered or flaked naphthalene $\frac{3}{4}$ in. deep which is covered over with about $\frac{1}{2}$ in. layer of sand. Naphthalene is essential to prevent the entry of khapra larvæ ; otherwise sand alone is sufficient against the adults of susri, sundwali susri, the two dhoras and the grain moth. The downward projecting ridge of the lid is pushed into the groove containing naphthalene

and sand. This serves as an effective barrier against the entry all insect pests of stored grains. Similarly the exit hole is covered wit a container having naphthalene an sand in it. The size of the bin and the top and exit holes can be regulate according to individual requirement Such bins can be conveniently mad by the cultivators cheaply.

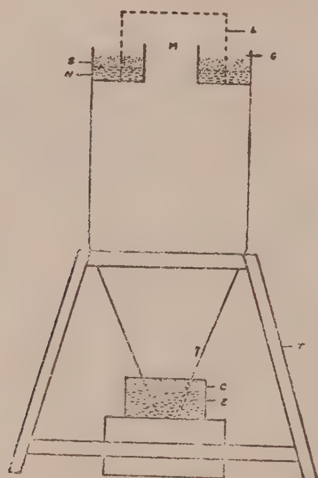


Fig. 9, Improved earthen bin. L, lid; M, top hole; G, groove; E, exit hole; T, tripod; S, sand; N, naphthalene

(*ii*) *Comparative susceptibility of im portant varieties of wheat to khapra.* Re lative susceptibility of different vari ties of wheat to the attack of khapr has been studied in the laboratory. I has been found that none of the existin varieties of wheat is completely im mune from its attack. Their relativ susceptibility has been found to depen upon their chemical composition. variety with higher protein content and dry glutin and low moisture con tents, is more susceptible to attack b khapra. Hardness or softness of th grain does not appear to have any im portance in relation to the attack this pest. Since the chemical composition of a variety is never constant bu varies considerably according to the nature of the soil, season, irrigatio etc. therefore, no one variety can be definitely said to be resistant under a conditions. In the present trials, 8 A has been found to be susceptible, C 51 and 9 D intermediate and C 591 comparatively resistant, to the attack khapra.

Observations were also made to study relative susceptibility of variou varieties of barley to the attack of khapra and it was found that : (*a*) the husk less varieties are attacked more than the husked ones. In one and the sam variety, naked grains are severely damaged while unhusked are very slightl damaged.

(*b*) Maximum attack was observed in 'Black No. 9' (35·6 per cent) an 'Lyallpur P' (20·6 per cent) among the huskless varieties and in 'Speci Two Rowed' (11·1 per cent) among the husked ones. 'Black' No. (3·9 per cent) in case of huskless and T 4 (0·5 per cent), 'Multan A' (0·5 pe cent) and 'Nowshera Four Rowed' (0·6 per cent) in case of husked vari ties were affected the least.

(*iii*) *Well-ventilated stores.* According to Cotes [1888] ventilation i stores causes the grain to be more infested by weevils while Fletcher [1923] of the opinion that grain stored in mud bins and dark stores is often mo heavily attacked than that in ventilated stores.

Experiments have to be conducted to decide this point finally but in th Punjab the effect of ventilation on the attack of khapra has been studied, an it has been found that, as khapra avoids light, both natural and artifici

darkness in stores favours its multiplication as is evident from Table III. This information was collected by keeping infested wheat in constant light and constant darkness.

TABLE III

Showing the effect of light and darkness on the attack of khapra

Treatment	Percentage of attack	Percentage of loss in weight
Light	6·5	1·5
Darkness	12·4	2·6

It would appear from the above table that it is better to have the stores well-ventilated particularly in localities where khapra is a serious pest.

CONTROL METHODS

(*i*) *Spreading of gunny bags, etc. over the infested grain to control khapra.* The larvæ and the adults—the larvæ more than the adults—of khapra have the peculiar habit of clinging to rough surfaces and this behaviour of the pest, which is called positive thigmotropism by scientists, is utilized for its control in open heaps of wheat. The entire heap of infested wheat is covered with gunny bags (Plate XXIV, fig. 1), tarpauline or any other rough cloth. The cloth is removed daily or on alternate days and shaken over an open receptacle containing water with a film of kerosene oil on the surface in order to throw into it all the larvæ clinging to the cloth (Plate XXIII, fig. 4). The cloth is again spread over the infested heap, removed and shaken as before, and this is repeated till the pest in the heap is brought under control. To give one example : a 20 maund heap of wheat was heavily infested with khapra : it had 24 living khapra insects *plus* innumerable eggs per gramme of wheat. Gunny bags were first spread on the heap on 4 September. Two thousand one hundred and eight to hundred and one thousand six hundred and fifty two larvæ and 541 to 94,811 adults of khapra were trapped daily by these gunny bags until 29 October when the population of the pest in the heap fell to one living khapra insect and no eggs per gramme of wheat. During the experimental period of 55 days, 1,267,855 larvæ and 236,857 adults were trapped and destroyed.

(*ii*) *Storing of wheat in open-air ' bharolas ' with glass lids to check khapra.* It has been found that if the temperature of the environment in which khapra lives is kept about 40°C. the multiplication of this pest is considerably restricted. Experiments have shown that solar heat is the best and the cheapest for the purpose. Therefore, to utilize solar energy for curbing the activities of khapra, ' bharolas ' should be constructed in the open, and after filling them with wheat, their open tops should be covered with glass lids (Plate XXIII, fig. 1) instead

of earthen lids as at present. The efficacy of 'bharolas' with glass lids in checking damage by khapra is shown in Table IV below :—

TABLE IV

Showing the percentage of attack by khapra in 'bharolas' with glass and earthen lids

	Percentage of attack
'Bharolas' with earthen lid	50·4
'Bharolas' with glass lid	15·6

Before fixing the lids 4000 khapra larvæ were introduced in each of the 'bharolas' containing wheat.

These glass lids should be kept on the open air 'bharolas' from April to September after which they should be replaced by the usual earthen lids. As solar energy is the chief factor in checking khapra, this method should only be adopted in tracts with scanty rainfall and a very hot summer, e.g. Lyallpur, Multan, Dera Ghazi Khan, Mianwali and Muzaffargarh districts.

(*iii*) *Storage of grain with a layer of sand on top*. This method has so far been tested against khapra, *moong* dhora and dhora. It has proved successful against *moong* dhora and dhora but is entirely ineffective against khapra. When healthy *moong* was stored under a layer of sand and exposed to infection, it was found to remain perfectly free from the pests as dhora adults were entirely unable to penetrate the sand layer and thus cause infection. Therefore, for keeping grain and pulses free from *moong* dhora and dhora, they should be stored in mud bins, metallic bins, or earthen vessels, with 1 in. thick layer of sand over their surface.

(*iv*) *Mixing of chemical dusts with grain to protect it from khapra and sundwali susri*. Chemical dusts are primarily recommended for treating grain intended for seed purposes only, but harmless and comparatively cheaper dusts may also be used for treating grain meant for human consumption.

So far the various chemical dusts mentioned below have only been tried on a laboratory scale. The grain mixed with them was kept in cloth bags and small earthen vessels plastered with a mixture of cowdung and mud. Each receptacle was artificially heavily infected, the grain in cloth bags being exposed to infection in addition.

Khapra :—Copper carbonate, sodium fluosilicate, katelsousse, tobacco dust, borax and sulphur were tried in varying doses against khapra. Copper carbonate (0·5 per cent by weight) and sodium fluosilicate (1·0 per cent) proved very effective and quick acting. Katelsousse (2·0 per cent), borax (1·0 per cent) and tobacco dust (2 per cent and 4 per cent), on the other hand, though effective were comparatively slow acting, thereby allowing some damage by the pest. Sulphur proved ineffective. In the treated samples, the percentages of attack were 0·28, 0·1, 4·4, 8·9, 8·0 and 60·7 in case of copper carbonate, sodium fluosilicate, katelsousse, tobacco dust, borax and sulphur respectively as against 100 per cent damage in the control (or untreated) lots. The percentage of loss in weight also varied almost in the same order.

Sundwali susri :—Against sundwali susri, copper carbonate (0·3 per cent), katelsousse (1·5 per cent) and sodium fluosilicate (1 per cent) proved equally effective. The percentages of attack in the treated samples were 2·5, 3·5, 95·6, 97·6, 27·4, 2·2 and 97·4 in case of copper carbonate, katelsousse, ash (4 per cent), tobacco dust (4 per cent), borax (2 per cent), sodium fluosilicate (1 per cent) and sulphur (2 per cent) respectively as against 99·9 per cent damage in the control (or untreated) lots.

None of the dusts mentioned above affected the germination of wheat except sodium fluosilicate which reduced it by 43 per cent.

From the above results it is evident that for treating the grain intended for seed purposes, copper carbonate at the rate of 0·3 per cent to 0·5 per cent by weight of grain should be thoroughly mixed with the grain which should then be stored in earthen vessels or gunny bags. Katelsousse, tobacco dust and borax, which are said to be non-poisonous, can be used for protecting grain meant for human consumption. Such grain should be thoroughly sieved and preferably washed, before being used for consumption.

(*v*) *Mercury*. Mercury is useful in keeping down the stored grain pests infesting earthen bins, metallic bins, bamboo bins, earthen vessels and wooden boxes, as is clear from Table V below. Because of its effectiveness, comparatively low recurring cost and ease in application, this method is very well suited for an ordinary householder and a small cultivator.

TABLE V

Efficacy of mercury in keeping down stored grain pests

Name of locality where experiment was performed	Percentage of damage in bins without mercury	Percentage of damage in bins with mercury	Remarks
Lyallpur	20·9	6·1	Efficacy of mercury depends upon the degree of air-tightness in the bin
Gurdaspur	30·7	2·1	
Jullundur	36·9	7·0	
Palampur	61·9	20·3	

Mercury is used at the rate of three to four tolas per maund of wheat. It is applied in twill or long cloth ('latha') bags each measuring 2 in. × 2 in. and each containing about one tola of mercury. These bags are evenly distributed in layers throughout the bin, with a 8 in. to 12 in. thick column of wheat between two successive layers. In case the grain is attacked by khapra alone, then the bags are distributed in the bin in such a way that the upper 10 in. to 12 in. receive about 44 to 47 per cent of the total quantity of mercury while the remaining quantity is uniformly distributed in the rest of the bin. The bin is then made air-tight. When the grain is taken out from the exit hole, the

mercury bags also come out with it. They should be picked up and carefull stored in some earthen receptacle for use in the next season. As very little c it is lost during use, mercury in twill bags can be used for many years. It ha no deleterious effect on the germination of seed or on its eating quality.

(*vi*) *Sun-drying of grain.* In foreign countries heat-treating machines i which the grain is subjected to temperatures of 130°F. to 140° F. for half a hour are employed to kill stored grain insect pests. These machines are not i vogue in India. The cheaper and equally effective way of heat-treating grai to kill such stored grain pests as khapra, susri, sundwali susri and the re flour beetle, in the Punjab is to spread the grain in the sun in very thin laye on a very hot and clear day during June and July for about five hours. Th grain should be disturbed every half an hour or so in order to expose the enti lot of grain to the direct rays of the sun. Most of these pests will die off whil others will try to escape by crawling to neighbouring shady places or back int the godowns : they should be prevented from escaping by digging a trenc round the place where wheat or other grains are receiving the heat treatmer and the insects trapped in these trenches should be gathered and destroyed.

(*vii*) *Heat treatment of empty godowns and store-rooms.* The heat trea ment of godowns, etc. is an effective and cheap method of killing all insect pes of stored grains : a temperature of 152°F. and above is fatal to all insects. Th treatment cannot be used in bins or 'khattis' ; it can only be used for treatin empty godowns, store-rooms, etc. during April or May to kill insect pes present in them.

General instructions for heat treatment. The floor, the walls and the ceilin of the godown, etc. to be heated should be thoroughly cleaned and all dirt an dust gathered and removed : it has been found by experiment that presen of dirt and muck in a room lowers the efficiency of the heat treatment : whe the floor temperature is 152°F. the temperature under 1 in. layer of di is only 117°F. The room should be made air-tight by closing with mud a cracks, openings and ventilators in it. Temporary brick furnaces (Pla XXIV, fig. 2) with an iron grating or a few iron bars in them should be co structed in the store-room. The number and size of these furnaces woul depend upon the size of the store-room ; for example in a store measurin 24 ft. × 23 ft. × 12 ft. ; two furnaces each capable of holding 10 to 15 seers charcoal are sufficient.

The quantity of charcoal is proportional to the number of cubic ft. in th enclosure. Therefore, before applying the heat treatment it is necessary t determine the cubic contents of the enclosure in accordance with the instru tions given on page 36 under hydrocyanic acid gas.

Charcoal is used at the rate of seven seers per 1000 cubic ft. of space. I case the store-rooms are of loose constructions, the quantity of charcoal shou be slightly increased.

When the preliminaries are completed and the room is made fit to recei the heat treatment, the furnace should be filled with charcoal which is set c fire (Plate XXIV, fig. 2). When the charcoal is fully ablaze and the smoke h ceased, the entrance door of the store-room under treatment should be le ajar so as to ensure a continuous draft of air to keep the charcoal burnin The remaining quantity of charcoal should be added to the furnace at interva

in small lots so as to bring about a slow and steady rise in temperature of the store-room : for example, the temperature of a store-room under treatment should rise at the following rate :—

Time	Temperature
9·45 A.M.	118°F.
10·45 A.M.	124°F.
11·15 A.M.	143°F.
11·45 A.M.	152°F.

The temperature of the room should be recorded on a maximum and minimum thermometer every half an hour till the room is closed. The thermometer should be placed on the floor farthest away from the furnace.

When the temperature of the room has risen above 150°F., the last instalment of charcoal should be added to the fire, the door should be closed completely and made air-tight by applying mud to the chinks and openings in it. The treated store-room should be left undisturbed for 48 hours after which it should be opened and allowed to cool. The thermometer should be removed after noting the highest temperature reached. The room should be thoroughly cleaned, its interior plastered with a mud-cowdung mixture so as to close all the cracks and crevices in its walls and floor. The fresh stock of grain should be stored in it when it has thoroughly dried.

Heat treatment of gunny bags. It has been mentioned under 'Sources of infestation' that gunny bags also harbour insect pests. To insure their destruction, old gunny bags, which are to be used for bringing in grain from outside or used for storing grain, should be thoroughly disinfected by being dipped in boiling water for about 15 minutes and then dried in the sun or being placed in the store-room while it is being given the heat treatment, after being turned inside out. Treated bags should again be placed in the sun for an hour or so just before use.

(*viii*) *Fumigation.* Certain chemical substances give off vapours which are most effective in killing all kinds of insect pests of stored grains and other insects. Chemicals so employed are called fumigants and the operation is called fumigation. Fumigants can only be applied to grains in air-tight enclosures and the fumigants more commonly used in the Punjab are hydrocyanic acid gas and carbon bisulphide. These fumigants can be used both for the disinfection of empty godowns, and for killing all kinds of pests when they are attacking grain stored in them.

Fumigation is the cheapest and most effective method for treating the infested grain in bulk storage especially when the containers are full to capacity.

Fumigation should only be carried out in the evening when the outside temperature is 70° F. to 100°F. and there is no strong wind blowing. The enclosure to be fumigated should be made air-tight by closing its cracks, ventilators and other openings with mud, etc. After fumigation is over doors or windows of the fumigated godowns should be opened from the outside. The dose of the fumigant is proportional to the number of cubic ft. in the godown which should be determined (before starting fumigation) by multiplying its length by its breadth and the product by its height. For example a room

20 ft. long, 16 ft. wide and 11 ft. high, will have a capacity of 20 ft. × 16 ft. × 11 ft. or 3,520 cubic ft.

General directions for fumigation with hydrocyanic acid. It is a highly poisonous and colourless gas which is produced by the action of dilute sulphuric acid on potassium cyanide. One pound of it spreads over about 14 cubic ft. of space at normal atmospheric pressure. It is lighter than air and spreads upwards and outwards in the atmosphere and it is for this reason that it does not penetrate deep into heaps of grain and sacks of flour. It is soluble in water and tarnishes brass, gold or nickel : to regain lustre these metals should be rubbed with polishing cloth.

Hydrocyanic acid is the deadliest poison known for all animals and for this reason operators working with this gas must handle it with the greatest caution : in fact it should only be applied by people well-versed in its use.

Hydrocyanic acid is employed for treating infested grain kept in open heaps, not more than 2 ft. deep or stored in gunny bags which are stacked in the godown. This gas is cheaper to use than carbon bisulphide.

There are four methods for applying hydrocyanic acid in an enclosure and of these the pot method is the cheapest and the most satisfactory for accuracy in dosage and for the type and scale of work usually done in the Punjab. Potassium cyanide, commercial sulphuric acid and water are the only materials required and they are mixed according to the following formula which is sufficient for 1,600 cubic ft. of space :—

Potassium cyanide (98 per cent purity)	1 lb.
Commercial sulphuric acid	1 lb. (by weight)
Water	3 lb.

Earthen vessels, stone jars or enamelled pans are used as generators and they are distributed at regular intervals in the room. First water is poured into these vessels to which the requisite quantity of acid is added ; these two liquids should together come to about $4\frac{1}{2}$ in. from the top of the generator. (These vessels should be able to withstand the heat which is generated by the reaction of the acid and water). Then the required quantity of potassium cyanide is wrapped in thick paper and placed near the generators. Each packet is then dropped into its generator, the operation starting with the generator farthest from the door. As soon as the last packet of potassium cyanide is dropped in the last generator the operator leaves the room and closes the entrance door from outside making it entirely air-tight. The room is kept closed for 24 to 36 hours after which the door is pushed open from outside from a distance with a bamboo pole. No one is allowed to enter the room until all traces of the gas have disappeared. The generators are then removed and their contents are buried in the ground and they are thoroughly cleaned. Earthen generators should be broken and buried.

General directions for fumigation with carbon bisulphide. It is a colourless, bad-smelling liquid which changes into gas very rapidly when exposed to air. It is more than $2\frac{1}{2}$ times heavier than air ; hence it always sinks to the bottom of the enclosure in which it is used. It is highly infammable and explosive, hence fire of any description, such as a lighted match stick, lighted charcoal, burning cowdung, lighted cigarettes or live ' hookah ' must never be brought near it or near the building in which it has been employed as a

fumigant. It is effective at temperatures of 75°F. to 90°F. and 1 lb. of it spreads over about 5 cubic ft. of space at normal atmospheric pressure. Because of its great penetrating powers, carbon bisulphide is used for treating thick columns of wheat, e.g. grain in bins.

The enclosure in which carbon bisulphide is to be used must be made entirely air-tight in the manner described under hydrocyanic acid. One oz. of carbon bisulphide is sufficient for 15 cubic ft. of space. In the room to be fumigated the liquid may be exposed in shallow earthen cups or it may be applied directly to the grain or be poured on rags and gunny bag pieces : whatever the method of application, the quantity to be used in an enclosure should be evenly distributed in it. When applied directly to grain it is liable to injure germination. It penetrates a column of grain to a depth of 6 ft. ; therefore, when the column of grain to be treated is deeper than 6 ft., metallic pipes or hollow bamboos with perforated sides plugged with cotton are inserted into the grain column and the fumigant is poured into them from above, to ensure uniform distribution of the chemical throughout the thickness of the grain heap. After the necessary amount of fumigant has been distributed the operator should leave the room at once and close the door from outside and make it air-tight. The rest of the procedure is the same as described under hydrocyanic acid. It may also be mentioned that carbon bisulphide in the dose suggested does not affect the germination of seeds like wheat, barley, *toria* and linseed.

Precautions during fumigation. The following precautions have to be observed during fumigation :—

(*a*) Potassium cyanide, being a deadly poison, should be handled with the greatest care and must never be touched with hand.

(*b*) Potassium cyanide should be stored dry in well-corked bottles or properly soldered tins.

(*c*) When the store-room to be treated is adjacent to residential buildings, their occupiers should be asked to vacate their quarters temporarily in order to avoid accidents through the leakage of gas.

(*d*) Carbon bisulphide should be stored in tightly stoppered or sealed bottles since it is volatile even under ordinary temperatures.

(*e*) Carbon bisulphide should be kept in a cool place especially during transit to avoid bursting of the bottles.

(*f*) Carbon bisulphide is highly inflammable ; no fire of any description should be brought near it or the treated store.

(*g*) Store-room being fumigated should be clearly labelled and carefully locked and guarded so that no body enters it until it has been thoroughly aired.

REFERENCES

Barnes, J. H. and Grove, A. J. (1916). *Mem. Dept. Agric. India* (*Chem. Ser.*). **4**, 165-280

Fletcher, T. B. (1911). *Agric. J. India* **6**, 333-343

Fletcher, T. B. and Ghosh, C. C. (1919). *Proc. 3rd Ento. Mtg. Pusa.* **2**, 712—761

Fletcher, T. B. (1923). *Proc. 5th Ento. Mtg. Pusa.* **1**, 236-237

Lefroy, H. M. (1906). *Indian Insect Life*, Thacker Spink & Co., Calcutta.

Rahman, Khan A. (1940). *Punjab agric. Coll. Mag.* **7**, 1-98

Rahman, Khan A. and Sohi, G. S. (1939). *Indian J. Ent.* **1**, 57-63

Rahman, Khan A. Sohi, G. S. and Sapra, A. N. (1942). (In press)

CONTROL OF THE WOOLLY APHIS *ERIOSOMA LANIGERUM* HAUSMANN) BY SPRAYING AND OTHER METHODS

BY

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THE woolly aphis is a very serious pest of apple trees all over the world. Its control in Kumaun orchards has been a very great problem ever since the fruit-growing industry was started in these hills sometimes towards the end of the last century. During this period various control measures recommended by foreign growers were tried by some of the enthusiastic orchardists, but every one of them had to be abandoned because of the prohibitive cost of the insecticides and their ineffectiveness in providing control in sufficient degree to warrant the incurring of heavy expenditure.

In 1934, with the appointment of the author as Entomologist in the Hill Fruit Research Scheme, work on the insect pests of orchards was started at Chaubattia and Ramgarh. Since then various methods of control have been under trial, the results of which have indicated certain definite conclusions. At this stage, the results of spraying trials against the woolly aphis carried out in the Kulu hills in the Punjab also having become available, it was considered desirable by the Imperial Council of Agricultural Research that results obtained in both the localities should be published together. For this purpose, the data received from the Punjab were placed at the disposal of the author which have been incorporated in the present contribution. Incidentally, this arrangement has shown how the same insecticide may produce different results under different environmental conditions.

From a review of the literature on woolly aphis it appears that nicotine spray is very effective against this pest. Tar distillate washes are also effective but in their case a very high concentration is necessary. Petroleum sprays late in the dormant period and 'summer-oil' sprays in the summer are also said to be quite effective. All these can, however, be effective only if they come in direct contact with the aphids, with the result that in very big colonies as well as in the cracks and crevices of the bark many aphids remain alive after a routine spraying of these.

For the control of woolly aphis on the aerial parts of the tree in summer, any insecticide, besides being an effective contact poison, should act as a fumigant also so that its vapours may reach the nymphs which remain hidden under their parents in big colonies and are not ordinarily reached by the spray. It has been fairly well established that nicotine acts as a fumigant, the active agent of which appears to be nicotine vapour which passes into tracheae of the insect and produces paralysis of the nervous system [McIndoo, 1916]. The importance of volatilization has also been demonstrated by de Ong [1923], who established a close correlation between the volatility of nicotine and its toxic action. Soft soap possesses a direct insecticidal

action besides being a spreader. A combined soft-soap-nicotine spray was. therefore, tried along with other contact insecticides for three consecutive years (1937-39) in order to test its relative effectiveness.

For the reasons stated above, nicotine spray cannot be so effective in winter as its volatilization at that time is very poor due to low temperature and it is very difficult to control the pest by ordinary contact insectides as it is protected by a mass of waxy filament secreted by it from the numerous wax glands on its back. It has been observed that in very thick colonies, although all the aphids on the surface are killed, a few remain unaffected under the dead ones even after a very thorough spraying . For any contact spray to be effective against this pest in winter it is, therefore, necessary that this cottony 'wool' is either completely washed off from its body or is dissolved by the spray material. Rosin-soap spray has been observed to act upon the 'wool' and wash it off. It is believed that it penetrates the tracheae and clogs the spiracles by a resinous deposit [Martin, 1928]. Different preparations of rosin soap were, therefore, tried at different places in Kumaun hills during 1936-38.

Besides the spraying trials, attempts were made in other directions also for the effective control of this pest and the possibilities of its control by means of soil fumigation, use of aphid-resistant stocks, grease-banding and natural enemies are briefly discussed.

Use of contact insecticides

Summer sprays

Laboratory trials with nicotine sulphate-oil emulsions and soaps

Material and method

Seventy plants of a highly susceptible stock, Malling type II, were potted in 9 in. earthen pots in January 1937 and shoots of all the plants were infected with woolly aphis in the following April. Fifty-six plants, having more or less uniform infection, were selected from the whole lot for the seven treatments mentioned below, each treatment being replicated eight times. The spraying was done in June 1937 from a close range by means of a hand sprayer at a pressure of about 75 lb. per sq. in. so that the white 'wool' was all washed off from the bodies of the aphids.

The strengths of the insecticides used were :—

1. Nicotine sulphate 40 per cent	1 oz.	
Soft soap	6 oz.	
Water	6 gallons	
2. Kerosene oil emulsion		
Kerosene oil	2 gallons	× 15 parts of water
Soft soap	½ lb.	
Water	1 gallon	
3. Fish-oil-rosin soap	1 lb.	
Water	6 gallons	
4. Summer spray 'S'	1 part	
Water	50 parts	
5. Nicotine sulphate 40 per cent	1 part	
Water	800 parts	

6. Soft soap . . . . . . 1 lb.
   Water . . . . 6 gallons
7. Control (sprayed with ordinary tap water)

Estimating effect of different sprays.—Cut pieces of twigs from the infeste portions of the plants were taken to laboratory 24 hours after spray ing and living and dead aphids were counted under microscope. The averag percentage mortality for each treatment is given in Table I.

The same experiment was repeated in 1938 and 1939 about th same time of the year with the difference that kerosene-oil-emulsion spra was used in a more concentrated form. This increased the percentage morta ity but scorched the tender leaves. This shows that kerosene-oil-emulsior when used as summer spray at effective strength, is harmful to apple trees The average percentages of mortality due to different treatments in 1938 an 1939 are also recorded in Table I.

TABLE I

Average percentage mortality of the aphids by different sprays in three year trials under laboratory conditions

Year of experiment	Nicotine sulphate and soft soap	Kerosene oil emulsion	Fish-oil-rosin soap	Summer spray 'S'	Nicotine sulphate alone	Soft soap alone	Control
1937	99·6	82·9	83·8	96·5	78·3	78·3	1 5
1938	99 5	94·1	99·9	100·0	99·3	98·7	13·9
1939	97·5	99·4	92·0	98·4	96·15	89·3	0·00
Average for three years	98·9	92·1	91·9	98·3	91·2	88·8	5·1

It will be seen from Table I that soft-soap-nicotine spray is most effective There is, however, no significant difference between this and summer spra 'S' but these two are significantly better than the other four. It will als be noticed that percentage mortality was much more in the latter two yea of the trial in the case of almost all the sprays. This was due to the fact th the colonies of the aphids were very small at the time of spraying and almo every individual was thoroughly drenched with the spray fluids. Suc condition is, however, very seldom met with when spraying is done on commercial scale.

Although a complete control of the pest may be effected with sever of the contact sprays mentioned above under laboratory conditions, eve soft-soap-nicotine spray, as will be seen later in this contribution, fails produce the desired effect in commercial spraying. Mr Greenslade of Ea Malling is also of the same opinion.*

*D. O. letter dated the 29 November 1937 from Mr R. M. Greenslade, East Mallin Kent, to the Secretary, Imperial Council of Agricultural Research, New Delhi

Field trials with combined soft-soap-nicotine spray

Materials and methods

To ascertain whether the difference in the results of experimental and routine spraying was due to the ranges of pressure and distances from the nozzle to the actual parts sprayed, experiments on field scale were carried out at Ramgarh in the years 1938 and 1939.

Thirty-six old apple trees, heavily infested with woolly aphis, were selected and the following nine treatments were randomized on them with one tree as the unit, replicated four times :—

1. Spraying from a distance of 3 ft. ; pressure between 75 and 51 lb. per sq. in.
2. Spraying from a distance of 3 ft. ; pressure between 50 and 26 lb. per sq. in.
3. Spraying from a distance of 3 ft. ; pressure between 25 and 15 lb. per sq. in.
4. Spraying from a distance of 2 ft. ; pressure between 75 and 51 lb. per sq. in.
5. Spraying from a distance of 2 ft. ; pressure between 50 and 26 lb. per sq. in.
6. Spraying from a distance of 2 ft. ; pressure between 25 and 15 lb. per sq. in.
7. Spraying from a distance of 1 ft. ; pressure between 75 and 51 lb. per sq. in.
8. Spraying from a distance of 1 ft. ; pressure between 50 and 26 lb. per sq. in.
9. Spraying from a distance of 1 ft. ; pressure between 25 and 15 lb. per sq. in.

Spraying was done in an orchard at Ramgarh by means of a four oaks spraying machine on June 7, 1938 at the strength recommended, viz. nicotine sulphate 40 per cent 1 oz., soft soap 6 oz. and water 6 gallons. On the following day, 20 twigs from each treatment were taken at random and the number of living and dead aphids were counted. The number of living and dead aphids on each twig and the percentage mortality under individual treatments are recorded in Table II.

It is evident from Table II that under the same treatment certain twigs had cent per cent mortality, while others had none at all. This was due to the fact that some colonies were not reached by the spray due to their inaccessible positions on the trees. It will also be seen that in blocks 1 and 2 there is cent per cent mortality on the twigs sprayed from a distance of 3 ft. at 25 and 15 lb. pressure, whereas there was no mortality at all on one of the twigs sprayed from a distance of 1 ft. at 75 and 51 lb. pressure. This shows that cent per cent mortality can be obtained even if the colonies are sprayed from a distance of 3 ft. at 25 and 15 lb. pressure, provided all the colonies are wetted.

This experiment was repeated in June 1939 with similar results.

Examination of individual colonies sprayed from different distances and at different pressures revealed that the difference between experimental and routine spraying was due to the fact that in the latter case some of the colonies were left untouched by the spray on account of their inaccessibility to it under ordinary field conditions. The ' wool ' was found to be intact in the case of colonies in which there was no mortality. It was observed that in the case of soft-soap-nicotine spray, it is not at all necessary that the ' wool ' should be washed off completely for the spray to be effective, as colonies with ' wool ' on, were found to have cent per cent mortality after the treatment. Only in very thick colonies with ' wool ' on, some nymphs were found living at the bottom.

TABLE II

*Number of living and dead aphids on each twig and percentage mortality after spraying with nicotine-soft-soap solution in 1938 at different distances and pressures**

Blocks	3 ft. 75 and 51 lb.		3 ft. 50 and 26 lb.		3 ft. 25 and 15 lb.		2 ft. 75 and 51 lb.		2 ft. 50 and 26 lb.		2 ft. 25 and 15 lb.		1 ft. 75 and 51 lb.		1 ft. 50 and 26 lb.		1 ft. 25 and 15 lb.	
	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D
	...	18	...	42	...	16	...	34	...	72	7	15	...	15	1	15	3	51
	...	30	...	21	...	60	...	20	...	50	3	15	...	16	10	32	2	16
1	2	20	...	21	...	45	...	24	...	40	7	15	...	17	15	63	...	8
	2	30	...	24	...	26	...	34	...	12	3	30	10	17	...	18	16	2
	4	41	...	15	...	50	...	44	...	20	...	8	...	56	...	22	4	1
Per cent mortality	94·6		100		100		100		100		80·6		92·4		84·7		75·7	
	...	4	...	42	...	3	...	9	...	19	...	14	1	14	7	30	...	14
	...	12	25	2	...	18	...	5	1	23	...	18	1	24	15	2	...	13
2	4	28	4	...	...	12	3	6	...	79	...	20	1	14	15	2	...	28
	...	20	5	5	...	14	...	6	...	19	...	22	2	10	4	20	3	20
	...	60	...	...	...	2	3	43	1	12	...	21	...	4	12	16	1	6
Per cent mortality	96·9		59		100		92		98·7		100		92·9		56·9		95·3	
	1	27	73	6	2	8	2	20	3	70	...	20	1	19	...	26	2	12
	...	42	...	10	20	...	1	22	1	14	...	28	1	14	...	24	1	13
3	...	18	3	15	12	...	...	15	1	43	1	50	...	6	...	46	...	20
	...	12	10	7	32	...	...	19	1	40	2	42	...	6	1	20	12	1
	...	42	4	45	20	32	...	13	...	15	...	26	...	11	...	60	2	...
Per cent mortality	99·3		47·9		31·7		96·7		97·3		98·2		96·5		99·4		73	
	1	20	26	7	6	30	...	17	7	7	...	39	2	30	17	22	3	7
	...	19	12	3	...	33	...	18	20	...	...	20	12	...	1	12	7	3
4	1	8	36	3	10	10	...	17	16	...	...	10	1	10	10	2	10	3
	1	8	14	3	...	13	...	32	18	18	1	10	...	12	2	60	1	17
	...	10	50	3	12	2	...	16	1	10	7	...	...	9	24	4	3	29
Per cent mortality	95·6		12·1		75·8		100		36·1		90·8		80·3		64·9		71·1	
[illegible]	96·5		54·7		76·9		97·2		83·2		92·4		90·5		76·5		78·8	

The above results were communicated to Mr Greenslade* who writes : 'The conclusion that in commercial spraying some colonies are left untouched must be correct, as I have found it impossible to obtain complete control even at 400 lb. per sq. in. although this gives a good commercial control. It is interesting to note that colonies were killed out by nicotine sulphate without complete wetting. In our climate I have only noticed this in warm weather, when using pure nicotine (98 per cent) at $\frac{1}{2}$ oz. in 6 gallons instead of the sulphate.'

Field trials with commercial nicotine sulphate (Black leaf ' 40 ')

As Black leaf ' 40 ' is said to contain 40 per cent nicotine, it was compared with chemically pure nicotine sulphate at 40 per cent strength with regard to its effect on woolly aphis.

Twenty-four apple trees having a large number of colonies on them were selected in an orchard at Ramgarh and divided into 12 groups of two trees each. The commercial and pure nicotine sulphates were sprayed on one tree in each group with a four oaks machine at a pressure of 40-60 lb. per sq. in. in the first week of June 1938. On the day following, four twigs from each tree were taken at random and the number of living and dead aphids found on them counted. Average percentage mortality under each treatment is given in Table III. From the results obtained it may be concluded that both are equally effective. Mortality is about cent per cent on most of the twigs in both cases. Colonies of living aphids had the ' wool ' intact on them, showing thereby that the spray did not wet them.

TABLE III

Average percentage mortality of woolly aphis with nicotine sulphate and Black leaf ' 40 ' at Ramgarh

	Blocks												
	1	2	3	4	5	6	7	8	9	10	11	12	Average Per cent
Black leaf '40	75·4	58·1	98·5	100	100	100	31·1	99·2	48·6	100	97·1	100	84
Nicotine sulphate 40 per cent	79·5	93·8	100	95·1	49·2	96·5	47·2	88·4	73·4	100	93·3	98·7	84·6

Trials with soft-soap-nicotine spray in the Punjab

Experiments with this spray were also carried out in the Kulu valley by the Entomologist to Government, Punjab, using the same dosages and

*Letter dated the 20th September 1938 from Mr R. M. Greenslade, East Malling Research Station, Kent, to the Imperial Council of Agricultural Research, New Delhi

pressures as were tried at Chaubattia. The following is the statement o the results obtained at Kulu as submitted by him to the Imperial Counc of Agricultural Research.

Results of spraying against woolly aphis in the Punjab

Material used for spraying	Formula	Mortality of aphids (per cent) — Distances from which sprayed: 1 ft.	2 ft.	3 ft.	Remarks
Nicotine sulphate and soft soap	Black leaf ' 40 ' 1 oz., soft soap 6 oz., water 6 gallons	7	7	5	Death was due to th insecticidal propert of the spray as we as breaking of th rostrum of aphid on account of over turning of individu als
Nicotine sulphate and water	1 : 800	1·5	1	1	Death was mostly du to the breaking c the rostrum c aphids
Soap and water alone	Soap 6 oz., water 6 gallons	7	6	3	Death was due t both the insecticida property of spra as well as breakin of the rostrum c aphids
Water	Water	1·5	0·5	0	Death was due t breaking of th rostrum of th aphids

These results apparently do not tally with the results obtained at Chau battia. As the atmospheric and temperature conditions are not mentione in the note of the Entomologist, Punjab, the author is inclined to believ that the disparity between the results of the two places might be due to thes factors. It may be well worth while investigating it.

Economics of the spray and method of its preparation

Commercial nicotine sulphate can be had at about Rs. 4 a pound whic will make about 100 gallons of spray, as it can be used at a dilutio of 1 : 800-1000. Even when used without soap, etc., it is as effective as mos of the contact insecticides, but with the addition of soft soap its toxicity very much increased. In fact, soft-soap-nicotine spray has proved to be th

most effective summer spray for the control of woolly aphis in the United Provinces. It is easy of transport and does not scorch the tender leaves. It should, however, be remembered that it cannot be so effective in winter as its chief value lies in being a fumigant also and in winter volatization is very little due to low temperature. The spray fluids must reach every colony. It is, however, very difficult to wet all the colonies in routine spraying as the aphids remain hidden in crevices in the bark and old galls, and besides they are protected by the leaves in summer. Even if a single aphid escapes, it reproduces parthenogenetically and the progeny starts new colonies in due course. To keep the pest under control, it is, therefore, necessary to repeat the operation from time to time. About two to three sprayings are usually necessary in a season. Total net cost of spraying 100 average-sized apple trees with soft-soap-nicotine spray comes to about Rs. 9.

To prepare 4 gallons of spray, 4 oz. of soft soap should be dissolved in hot water and diluted to 4 gallons of water. Twenty-two c.c. of nicotine sulphate should be added to it and stirred well to get the material thoroughly mixed.

WINTER SPRAYS

Trials with rosin soap and oil emulsions at Chaubattia

Tar-oil emulsion, fish-oil-rosin soap and kerosene-oil emulsion were tried against woolly aphis on dormant apple trees at Chaubattia during three consecutive years (1936-38).

Material and method

Twenty-four plants of an apple stock, Malling type II, which is very susceptible to woolly aphis attack, were potted in July 1936 and shoots of all the plants were infected with about 300 aphids in the following September. In December of the same year 20 plants, more or less uniformly attacked, were selected and divided into four groups of five plants each for the four treatments mentioned below :—

The strengths of the insecticides used were :—

1. Tar-oil (yellow, thin, light oil, M/3 brand), 10 per cent
2. Fish-oil-rosin soap, 3 lb. in 10 gallons of water
3. Kerosene-oil-emulsion soap 1 lb. }
   Kerosene-oil 2 gallons . . } Diluted with 10 parts of water before spraying
   Water 1 gallon . . . . . }
4. Control (sprayed with ordinary tap water, temperature 8°C)

The spraying was done in December 1936 from a close range by means of a four oaks machine at 75-100 lb. pressure. On the following day of spraying, attacked portions of the shoots of all the 20 plants were taken to the laboratory and the living and dead aphids found on them were counted.

The experiment was repeated in December 1937 and 1938.

Average percentage mortality of the aphids for the three years trials are given in Table IV.

TABLE IV

Average percentage mortality of the aphids by different dormant sprays in thre years trials under laboratory conditions

Year of trial	Fish-oil-rosin soap	Tar-oil emulsion	Kerosene-oil emulsion	Control (sprayed with cold water)
1936	92·8	75	76	14
1937	91·85	100	76·83	11·83
1938	90·3	88·4	99·7	1·35
Average for three years	91·65	87·8	84·18	9·6

Discussion of the results.—Fish-oil-rosin soap gave about 90 per cent kil in each year but the effects of others were not uniform. Hundred per cen mortality with tar-oil emulsion in 1937 was very probably due to the fac that the oil was not well emulsified as the colonies on examination looked a if they were sprayed with tar-oil. The unemulsified oil remains on the surfac of the spray material and as only five plants were sprayed, it is possible tha they were sprayed with free oil instead of its emulsion, although no injur to the plants was noticed, as they were in a dormant condition. To confirm this fact several trials with tar-oil emulsion were made in the winter of 1938 but in every case mortality was less than 88·5 per cent. Same was th case with kerosene-oil emulsion in 1938, when it proved most effective.

Examination of the individual colonies of woolly aphis sprayed with fish oil-rosin soap showed that almost every aphid touched by the spray was killed That the mortality of the pest was only about 90 per cent with thi spray was mostly due to the fact that some aphids escaped the spray.

Trials with rosin soap (on field scale) at Ramgarh

Rosin soap, creosotated-rosin soap, creosole-rosin soap and tobacco-rosi soap were prepared in the laboratory at Chaubattia. These along with th commercial fish-oil-rosin soap were tried on a field scale in December 1939 i an orchard at Ramgarh. Thirty average-sized apple trees were selected fc the five treatments, each treatment being replicated six times. Five rando samples of twigs were taken from each tree 24 hours after sprayin and living and dead aphids on each twig were counted under microscop The average percentage mortality for each tree is recorded in Table V.

TABLE V

Percentage mortality of the aphids under different treatments

Serial No.	Rosin soap	Creosotated-rosin soap	Creosole-rosin soap	Tobacco-rosin soap	Fish-oil-rosin soap
1	79 ·5	84 ·4	95 ·6	97 ·9	96 ·6
2	80 ·0	89 ·0	100 ·0	100 ·0	92 ·7
3	60 ·2	98 ·6	94 ·2	100 ·0	95 ·8
4	83 ·0	100 ·0	98 ·5	100 ·0	88 ·3
5	64 ·3	93 ·2	92 ·6	99 ·5	92 ·0
6	84 ·6	90 ·3	90 ·1	100 ·0	84 ·6
Average	75 ·3	92 ·6	95 ·0	99 ·6	91 ·0

The analysis of the data shows rosin soap to be significantly inferior to the other four.

Trials with rosin soap in the Punjab

Different varieties of rosin soap were tried against woolly aphis by the Entomologist to Government, Punjab, in the month of November. The results obtained, as submitted by him to the Imperial Council of Agricultural Research, are given below :—

(1) *Rosin soap*—
- *Mahwa* oil . . . . 4 lb.
- Caustic soda . . . . 1 lb. 5 oz.
- Rosin . . . . 6 lb.
- Water . . . . 4 lb.

(2) *Gas-tar-rosin soap*—
- As No. 1
- Gas tar . . . . 4 oz.

(3) *Creosotated-rosin soap*—
- *Mahwa* oil . . . . 4 lb.
- Rosin . . . . 6 lb.
- Caustic soda . . . . 1 lb. 5 oz.
- Water . . . . 4 lb.
- Creosote oil . . . . 4 oz.

(4) *Creosole-rosin soap*—
- As No. 1
- Creosole . . . . 4 oz.

(5) *Tobacco-rosin soap*—
- As No. 1
- Tobacco extract (1½ lb. tobacco boiled in 6 lb. of water)

(6) *Pure tobacco soap*—
- *Mahwa* oil . . . . 9 lb.
- Caustic soda . . . . 1¼ lb.
- Tobacco extract (1½ lb. tobacco boiled in 6 lb. of water)

Seriously affected trees were selected for trial. The pest was present in all stages. Table VI gives the results of the trials.

TABLE VI

Mortality of aphid with various strengths of soap in the Punjab

No.	Variety of soap	Strength used and mortality obtained (per cent) (quantity of soap in 40 lb. of water)				
		6 oz.	8 oz.	10 oz.	12 oz.	14 oz.
1	Rosin soap	29	45	84	98	100
2	Creosotated-rosin soap	32	48	88	100	100
3	Gas tar-rosin soap	32	48	88	100	100
4	Creosole-rosin soap	32	48	88	100	100
5	Tobacco-rosin soap	31	48	88	100	100
6	Pure tobacco soap	21	52	52	56	75

SOIL FUMIGATION AGAINST THE WOOLLY APHIS ON ROOTS

Control of woolly aphis on the roots of the apple trees by soil fumigation with paradichlorobenzine, carbon disulphide and tobacco dust has proved effective to a certain extent in some countries [Greenslade, 1936], but Leach [1926] found that effective dosages of carbon disulphide damage the roots as well. An experiment with six kinds of soil fumigants, viz. paradichlorobenzine, carbon disulphide, carbon disulphide emulsion, naphthalene, Seekay-soil-fumigant and Shirlan, was carried out at Chaubattia on potted apple plants in two consecutive years. Only paradichlorobenzine and Seekay-soil-fumigant proved effective ; but as about 60 per cent of the plants died under these treatments, their use at effective strengths is injudicious. From this and other considerations, no further trials with soil fumigants were carried out at this station. The effect of soil fumigants is not quite permanent and so they are required to be applied to every tree several times during a year. This is not only expensive but a very laborious operation in the hill orchards. Soil fumigants may economically be used in nurseries but cleaning of the aphids from roots of non-resistant stocks will not help much as these will again be attacked when transplanted.

USE OF APHID-RESISTANT STOCKS

The problem of controlling woolly aphis on the roots of trees can easily be solved if aphid-resistant stocks possessing desirable horticultural qualities are used. The relative susceptibility of the important Malling types and Merton 779 and 793 was tested under controlled conditions in 1936. Both

the Merton types remained free throughout the season. Among the Malling types, type XIII was found to be significantly more resistant than the rest The three resistant stocks were again tried in 1937 in different types of soils to see if they remained resistant in all kinds of soils. *Pyrus baccata*, an indigenous species on which woolly aphis has never been seen in nature, was also included in the trial. Results showed that the two Merton types and *P. baccata* remained practically free of the aphids in all kinds of soils. The two Merton types have been included in a field-scale-replicated trial of stocks for studying their other horticultural qualities.

In 1938, eight promising local types of stocks, *Pyrus baccata* and two new Merton types Nos. 778 and 789 were similarly tried. Of these *P. baccata* remained absolutely free and the two Merton types were found to be significantly more resistant than Malling type XIII, which is the most resistant among all the Malling types. *P. baccata* having remained quite free for two consecutive years under controlled conditions was sent to the nursery for propagation and the two Merton types Nos. 778 and 789 were tried for a second time in 1939. In the second year of the trial also they remained practically free from the woolly aphis, and hence they were included among the highly resistant stocks and sent to the nursery for further studies with regard to their horticultural qualities.

Since 1939 relative resistance of some very vigorous Russian seedlings, which have not been attacked by woolly aphis in the nursery, is being tried under controlled conditions. From the observations made so far, it appears that a few of them will prove to be very highly resistant to woolly aphis and some of these might be possessing other desirable qualities also.

Grease-banding of trees

Large number of wandering young aphids are caught on grease bands, but the observations on the migrations of woolly aphis made at this station have shown that grease-banding cannot effect a check on them to any appreciable extent.

Migration of the aphids from roots to shoots and *vice versa* goes on simultaneously for the whole of the year except for a period of about two months during the coldest part of winter. Grease bands will, therefore, have to be maintained for the whole year to check the migration from one part of the tree to another. Even then it is hardly possible to save either the roots or the aerial parts due to various other sources of infection. An experiment on a field scale was carried out at Chaubattia for two consecutive years to ascertain if the aerial parts of apple trees can be kept free from woolly aphis by spraying the trees thoroughly in early spring and maintaining the grease bands throughout the year to check the infection from roots. The formation of colonies of woolly aphis on the aerial parts of the trees was not checked even by this method. This might have been due to one or more of the following reasons :—

(*a*) As the hibernating nymphs spend the winter in cracks in the bark, and colonies are mostly on the underside of the branches, it is possible that some individuals might not have been reached by the spray

(*b*) As the aphid reproduces parthenogenetically, even a single individual left on a tree could have started a colony

(c) As a large number of winged asexual females are produced in August and September, they might have blown off to other trees and started new colonies

It thus appears that grease-banding can only effect some reduction in the number of the aphids on the trees, but it should not be relied upon as an effective control measure.

Natural enemies

Predators

Woolly aphis is preyed upon by various predacious insects. Greenslade [1936] has given a list of about 50 species recorded from all over the world. In Kumaun we have not got many of these but a lady-bird beetle, *Coccinella septempunctata* Linn. is of immense economic importance to the orchardists of these hills. It appears in large numbers towards the end of March and attacks almost every colony that it can find on the aerial parts of the trees. The beetles remain very active till about the end of June, and that is the main reason why only a few colonies are seen on apple trees during this period. The number of predator beetles decreases after June ; when some of them migrate to green vegetation where they find plenty of aphids of different species. They do not, however, disappear altogether from apple trees before the beginning of October. The number of colonies of woolly aphis goes on increasing slowly during the rainy season and more rapidly after September till about the end of November. In the absence of the *Coccinellid* beetle, which starts hibernating after September, and also due to excessive reproduction in the months of October and November, the pest assumes a very virulent form in the autumn. Syrphid larvae, *Syrphus confrater* Wied., become visible on many colonies after September and they remain active till the end of November but they do not seem to effect much check. Chrysopa larvae are only rarely seen attacking woolly aphis in Kumaun.

Parasites

Aphelinus mali Hald. is known to occur naturally in the United States of America and Canada where it keeps the woolly aphis in check. It has been used for over 0 years as a parasite of woolly aphis in various countries and in some countries its usefulness is now fairly established. In Italy, it is very effective and in France and England also partial success has been obtained.

The parasite was introduced in the Punjab in 1936 and since then it is being multiplied inside breeding cages which have been put up in several of the orchards. It is reported by the Entomologist to Government, Punjab, that the parasite has proved quite effective in controlling woolly aphis in the Punjab.

In Kumaun it is very doubtful if the parasite can establish itself in nature due to the presence of the predator beetle which hardly allows any colony of woolly aphis on the aerial parts of the trees from March to the end of June. It can, however, be reared successfully inside wire-gauge cages which the predators cannot get into. The first attempt to breed the parasite inside such cages was made at Chaubattia and Ramgarh simultaneously in 1931 and at both the places a few generations of the parasite were observed inside the cages, but the adult flies which emerged about the middle of May died without parasitizing the aphids.

In view of the promising results reported about this parasite from the Punjab, attempts to breed *Aphelinus mali* artificially in cages have again been under way since 1940. Observations so far made seem to indicate that during late autumn and winter, when the aphid colonies appear in large numbers, the parasite, even if multiplied artificially in cages and released in the orchards, finds itself unable to keep pace with the reproductive rate of the pest and destroys only a limited proportion of the woolly aphis colonies. The orchardists, therefore, cannot get over the necessity of applying winter washes on their apple trees which makes the employment of the parasite a somewhat superfluous procedure. Nevertheless, experiments to test the rate of multiplication and spread of *Aphelinus mali* are being continued in order to assess the value of the parasite thoroughly before pronouncing final judgement on its effectiveness in the Kumaun orchards.

Conclusions

It will be seen from the experiments described above that the woolly aphis on the aerial parts of the tree can most effectively be controlled by a lady-bird beetle (*Coccinella septempunctata* Linn.) and by spraying the affected parts with a suitable contact insecticide. Soft-soap-nicotine spray has been found to be most suitable for spraying in summer and creosole or tobacco-rosin soap in winter. Observations made so far have indicated the possibility of controlling the root colonies by the use of aphid-resistant stocks. As far as control by *A. mali* is concerned, the effectiveness of this method, as already pointed out, is still to be finally established.

Summary

Results of trials of summer sprays carried out at Chaubattia and Ramgarh in the Kumaun hills during 1937-39 have very clearly indicated that woolly aphis can be controlled with contact insecticides such as rosin-soap, oil-emulsion and soft soap, but as these can act only when they actually come in contact with the insect, every individual must be touched by the spray fluid. This is, however, seldom possible in routine spraying, especially when there are big, old colonies. In such colonies a few young aphids remain quite safe under their dead parents and, besides, the nymphs which happen to be in the crevices of the bark at the time of spraying are not reached by the spray.

A combined soft-soap-nicotine spray, besides being an effective contact insecticide, acts also as a fumigant. By various trials carried out at Chaubattia and Ramgarh it has been found to be the most effective among all the summer sprays tried. In the case of this spray, it is not necessary that the waxy threads should all be washed off from the body of the insect for the spray to be effective. Even if the colonies are sprayed from a distance of 3 ft. and at a very low pressure, there may be cent per cent mortality, provided all colonies are touched by the spray. In commercial spraying even this spray sometimes fails to give 100 per cent kill owing to the fact that some aphids remain protected in cracks and crevices of the bark and they are protected by leaves also. Complete control of the pest is, therefore, dependent upon the thoroughness of spraying. Soft-soap-nicotine-sulphate spray should be used only in summer as the evaporation of nicotine in winter is too slow to be effective.

In various trials carried out at Chaubattia, resin-soap spray has been found to be the most effective contact insecticide for controlling the pest during winter. Field-scale experiments carried out at Kulu by the Entomologist to Government, Punjab, and at Ramgarh by the author show that 100 per cent mortality can be obtained with this spray if a little creosole or tobacco extract is added to it.

Under Kumaun conditions it has not been found practicable to control the root colonies by means of soil fumigants. Observations on the relative susceptibility of stocks to this pest have indicated the possibility of its control on the underground portions of the tree by the use of aphid-resistant stocks. Grease-banding near the base of the tree checks the infection of aerial parts from roots, but as there are other sources of infection and the aphid reproduces parthenogenetically, the aerial parts get fully covered with colonies even if the grease band is maintained throughout the year. The lady-bird beetle, *Coccinella septempunctata*, keeps the pest under check for the greater part of summer and consequently the parasite of the latter, *Aphelinus mali* Hald., cannot establish itself in nature. The parasite can, however, be made use of to a certain extent, by breeding it under controlled conditions inside a suitable cage in every orchard.

Acknowledgements

The experiments were carried out at Chaubattia and Ramgarh (Kumaun hills) under the Hill Fruit Research Scheme, financed by the Imperial Council of Agricultural Research (India). Thanks are due to Dr K. B. Lal, Entomologist to Government, United Provinces, for going through the manuscript and making certain valuable suggestions.

References

de Ong, E. R. (1923). *J. Econ. Ent.* **16**, 48

Greenslade, R. M. (1936). *Tech. Comm. No.* **8**, *Imp. Bur. of Fruit Production*, p. 13-5

Leach, B. R. (1918). *Bull. U. S. Dept. Agric.* **730**, 24-46

——— (1920). *Soil Sci.* **10**, 421-62

Martin, H. (1928). *The Scientific Principles of Plant Protection*, p. 142. Edward Arnold & Co., London.

McIndoo, N. E. (1916). *J. agric. Res.* **7**, 89

ADDENDUM

Since submitting the paper for publication, the author has come across two recent publications in India dealing with the pest, *Eriosoma lanigerum* and its parasite, *Aphelinus mali*, by Rahman and Khan (*Indian J. Agric. Sci.* **11**, 265-78; 446-50; 1941) but the points of issue discussed in the body of this paper remain unaffected.

STUDIES IN THE PERIODIC PARTIAL FAILURES OF THE PUNJAB-AMERICAN COTTONS IN THE PUNJAB

*VI. THE EFFECT OF SODIUM SALTS ON GROWTH OF PLANTS AND DEVELOPMENT OF *TIRAK*

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(With Plate XXV and 12 text-figures)

THE soil conditions associated with *tirak* or bad opening have been described in a previous contribution [Dastur and Samant, 1942] and it was pointed out that one of the soil types where *tirak* occurred contained sodium salts in the subsoil either in soluble form or exchangeable form or both. Such soils may be sandy loams or light sandy soils. If the soils are light sandy they are also deficient in nitrogen and both soil conditions that are associated with *tirak* are found to occur together.

Tirak symptoms generally develop at the fruiting stage and it would be interesting to study the growth of plants on normal and saline soils from the seedling stage up to maturity so as to know at what stage the functional activities of the plants begin to be influenced by the saline conditions in the subsoil.

The toxic effects exercised by alkali salts on various kinds of plants have been known and the effects of different concentrations of different salts of sodium on different plants have been investigated with a view to determining the limits of tolerance of plants to different salts. Amongst the investigators who have worked on this aspect of alkali salts, Hilgard [1906], Harris [1920], Headley, Curtis and Scofield [1916] and Hibbard [1925] may be specially mentioned. It is now known that sodium carbonate and sodium chloride are more toxic than sodium sulphate and sodium bicarbonate. It is also known that the limit of salt tolerance would depend on the physical structure of the soil.

The toxic effect of sodium chloride on the growth of citrus trees has already been recorded by Hilgard [1906]. He has also shown that toxicity of sodium salts on citrus trees was great when even small quantities of sodium chloride were present. Similar conclusions have been reached by Neidig and Magnuson [1924]. Theron [1937] found that sudden defoliation of citrus trees was caused by the presence of alkali salts in the soil. The deleterious effects exerted by these salts were due to their effect on the physical structure of the soil. Voelcker [1916] had also found that sodium chloride was most toxic when present in concentrations of 0·2 per cent.

* The work reported in the paper was done in the Punjab Physiological (Cotton Failure) Scheme financed jointly by the Punjab Government and the Indian Central Cotton Committee

The limit for salt tolerance is low in sand and high in clay. Harris [1915] has shown that only half the quantity of an alkali salt is required to prohibit the growth of crops in sandy soils as compared with the quantity required in loamy soils. Harris and Pittman [1918] have shown that salt tolerance is greater in loam soils than in either sand or in clay.

The moisture content of the soil plays an important part in salt resistance of plants. Increase of moisture up to a limit at which growth can occur will increase the salt resistance. The percentage of soil moisture will influence the toxicity. If the moisture supply diminishes, the salt tolerance is also reduced [Harris, 1915].

The injurious effects of an alkali salt can be reduced by addition of calcium salts as there is a strong antagonism between sodium and calcium ions [Harris, 1915].

The salt tolerance of a plant is also influenced by temperature. Ahi and Powers [1938] have found that at high temperatures salt tolerance of grasses and legumes decreased, while their resistance to salts increased at low temperatures.

A large amount of work is done to study the effect of alkali salts in culture solutions on the growth of plants, especially by Breazeale [1916], but the results obtained under culture solutions were not found to apply under soil conditions.

The above review indicates that the toxic effects of alkali salts on plants have been known, but no definite information exists on the growth of plants on saline soils under natural conditions. It is known that certain crop plants like wheat, barley and others are more resistant to alkali salts than legumes and fruit trees. The effect of alkali salts on the plant structure is also known. The plants become succulent with dark green and fleshy leaves where alkali salts are present. Very little definite information, however, exists on the growth of a plant like cotton on soils which are saline in the subsoil. Kearney and Scofield [1936] found that magnesium compounds were more toxic to cotton seedlings than other salts. Joseph [1925] has mentioned that the yields of seed cotton were reduced in fields which contained sodium salts in the subsoil but no detailed study of the growth has been made.

In a previous contribution [Dastur and Samant, 1942] it has been shown that, in the Punjab, salinity in the subsoil was associated with *tirak* or bad opening of the bolls in American cottons. It was, therefore, necessary to study the growth of the cotton plant under known conditions of soils.

If salinity in the subsoil is responsible for causing this type of physiological disease in American cottons, it is necessary to obtain experimental evidence to support this finding. It was, therefore, undertaken to find out if similar effects on the growth of the plants as are found under natural conditions can be reproduced by the application of sodium salts to a soil which is normal, i.e. which is non-saline.

The present investigation, therefore, deals with : (1) a study of the growth of cotton plants on soils which are known to be saline in the subsoil, and (2) a study of the effects of the applications of different sodium salts to normal soils, on the growth and yield of American cotton plants. Such a

study would tell whether the symptoms similar to *tirak* can be reproduced by applications of any one of the sodium salts or not and it would thus enable us to confirm the fact that the salinity in the subsoil was causing *tirak* in the Punjab.

Investigation

I. Growth of American cottons on soils with saline subsoil

Three types of fields were selected for this investigation where the soil conditions and the conditions of the crop in each case were already known. (1) Field with sandy loam soil where there was no salinity and where there was no *tirak*, (2) field with sandy loam soil where the subsoil was heavy and saline and where *tirak* had occurred and (3) field with light sandy soils deficient in nitrogen and with a saline subsoil and where *tirak* had occurred in the previous season.

The growth of plants under each case was measured by recording the increase in height at short intervals and by taking the dry weights of a unit of 5-10 plants at regular intervals. Various observations were made on the shedding percentage of leaves, daily rate of flowering and the setting percentage of total flowers produced. The number of bolls per plant and the yield were also recorded.

For getting a numerical expression of *tirak* or bad opening, the weight of seed cotton per boll was taken as that was the best criterion for expressing *tirak*. In *tirak* plants the bolls crack with immature seeds with very trashy lint. The weight of seed cotton per boll would indicate the degree of immaturity of seeds and consequently bad opening.

The dry weights of the different parts of the plants under saline and non-saline conditions of the light sandy soil are given in Table I. The presence of sodium salts decreases the production of dry matter. As the dry weight data was collected separately in five plots with normal and saline subsoil each, the results were analysed by the method of analysis of variance. The dry weight per plant under saline conditions was significantly lower than the dry weight per plant under normal conditions (Table I).

TABLE I

Dry weight, height, boll number, weight of seed cotton per boll and yields of 4F American cottons on normal soil and soil with saline subsoil

(Light sandy loams)

Observations	Normal	Saline	Difference (normal—saline)	S. E.
Total dry weight in gm. per plant	438 ·3	363 ·9	74 ·4*	±26 ·8
Final height in cm. per plant	113 ·2	99 ·2	14 ·0**	±4 ·36
No. of bolls per plant	31 ·0	31 ·9	—0 ·9	±2 ·07
Weight of *kapas* per boll in gm.	2 ·11	1 ·56	0 ·55**	±0 ·81
Yield in lb per plot	25 ·56	17 ·79	7 ·77**	±1 ·45

* Significant at 5 per cent level ** Significant at 1 per cent level

Though the actual dry weight per plant is reduced under saline conditions, the percentage increase in dry weight at successive stages of growth does not vary under normal and saline conditions (Fig. 4) in case of light sandy soils. The case is different for sandy loams with a heavy subsoil containing large amounts of sodium salts (Fig. 3). In this case the percentage increase on dry matter at different stages is depressed.

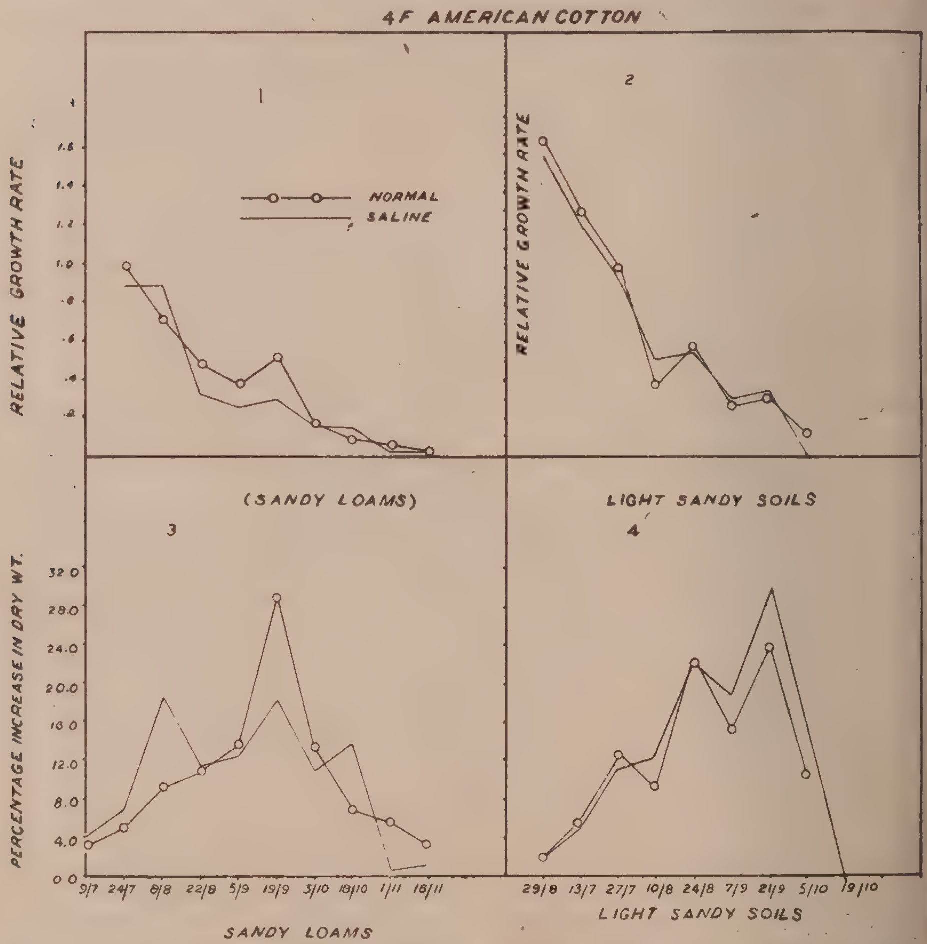

FIG. 1. Relative growth rates of 4F American plants in sandy loams with normal and saline subsoils

FIG. 2. Relative growth rates of 4F American plants in light sandy soils with normal and saline subsoils

FIG. 3. Percentage increase in dry weight in 4F plants on sandy loams with normal and saline subsoils

FIG. 4. Percentage increase in dry weight in 4F plants on light sandy soils with normal and saline subsoils

The relative growth rates of plants are given in Figs. 1 and 2 and their net assimilation rates in Fig. 5, under normal and saline conditions. The trends in the relative growth rates as well as net assimilation rates under normal and saline conditions are almost similar.

The salinity in the subsoil significantly decreased the extension growth as can be seen from Tables I and II and Figs. 6 and 7. The decrease in height is greater under saline conditions in sandy loams (Fig. 6) than in light sandy soils (Fig. 7). The premature shedding of leaves was found to occur under saline conditions.

TABLE II

Final heights, boll numbers, opening and yields of American and desi *plants on sandy loams with normal and saline subsoils*

	Final height in cm. per plant				Wt. of seed cotton per boll in gm.			
	Mol. 39	4F	Mean	Mean diff. Mol. 39—4F	Mol. 39	4F	Mean	Mean diff. Mol. 39—4F
Normal subsoil	160·2	115·2	137·7	45·0	1·40	2·13	1·76	—0·73
Saline subsoil	110·0	83·4	96·7	26·6	1·37	1·58	1·47	—0·21
Mean	135·1	99·3	117·2	35·8	1·38	1·85	1·62	—0·47
Mean diff. normal—saline	50·2	31·8	41·0	9·2	0·03	0·55	0·29	—0·26

Main effects with S. E.		Main effects with S. E.	
Soil	41·0±4·81**	Soil	0·29±0·138*
Variety	35·8±4·81**	Variety	—0·47±0·138**
Interaction	9·2±4·81	Interaction	—0·26±0·138

	No. of bolls per 12 sq. ft.				Final yield of *kapas* in gm. per 12 sq. ft.			
	Mol. 39	4F	Mean	Mean diff. Mol. 39—4F	Mol. 39	4F	Mean	Mean diff. Mol. 39—4F
Normal subsoil	188·0	64·8	126·4	123·2	267·8	139·4	203·6	128·4
Saline subsoil	93·8	54·6	74·2	39·2	129·2	87·2	108·2	42·0
Mean	140·9	59·7	100·3	81·2	198·5	113·3	155·9	85·2
Mean diff. normal—saline	94·2	10·2	52·2	42·0	138·6	52·2	95·4	43·2

Mean effects with S. E.		Mean effects with S. E.	
Soil	52·2±12·04**	Soil	95·4±24·3**
Variety	81·2±12·04**	Variety	85·2±24·3**
Interaction	42·0±12·04**	Interaction	43·2±24·3

* Significant at 5 per cent level ** Significant at 1 per cent level

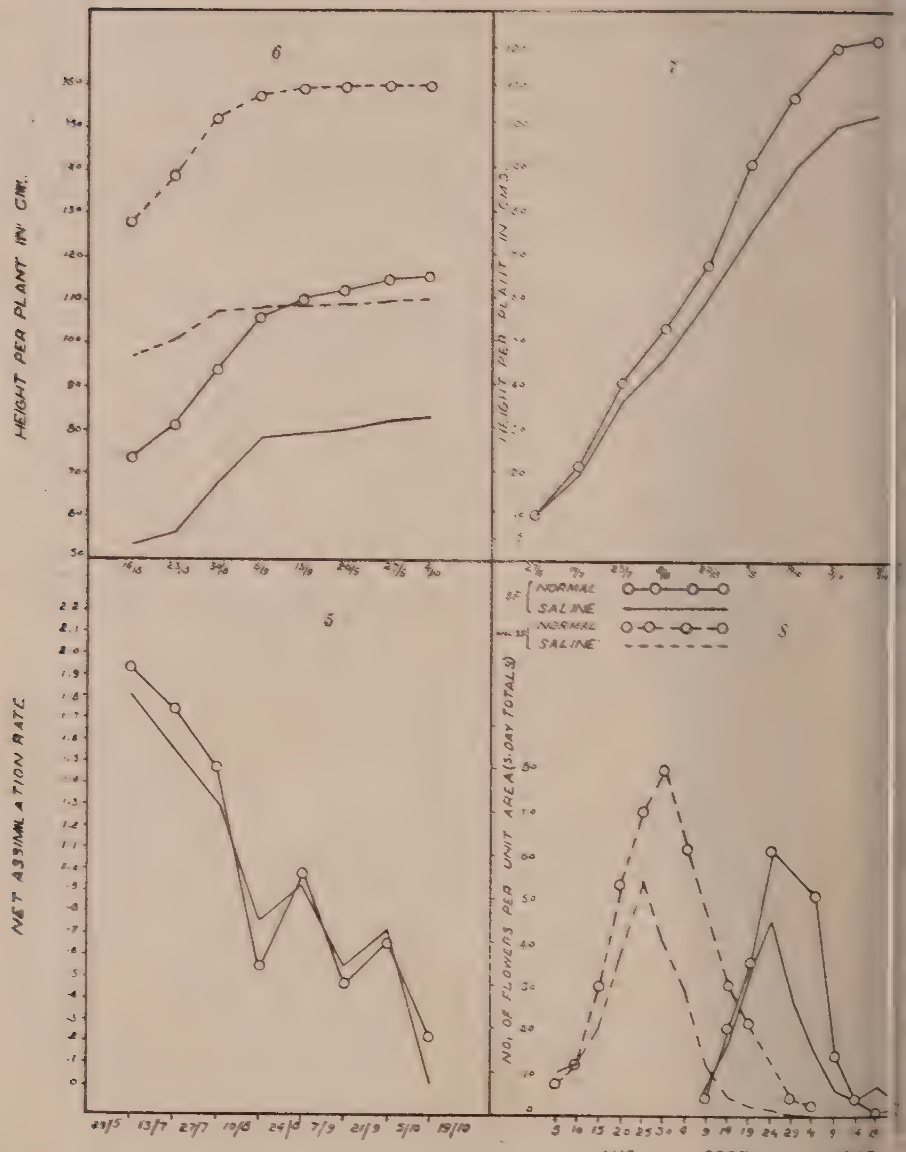

FIG. 5. Net assimilation rates of 4F plants on light sandy soils with normal and sali subsoils

FIG. 6. Height in cm. per plant of 4F American and Mollisoni *desi* plants on sand loams with normal and saline subsoils

FIG. 7. Height in cm. of 4F American plants on light sandy soils with normal and sali subsoils

FIG. 8. Flowering rates (5-day totals per unit area) of 4F and Mollisoni plants on sand loams with normal and saline subsoils

Fig. 1. Normal position of leaves of 4F cotton plants on sandy loam (30.9.38)

The number of bolls produced per plant or per unit area are not found to be reduced under saline conditions in light sandy soils (Table I). As a result of measurements made in different plots it was found that the number of bolls produced per plant under saline and normal conditions were nearly equal (Table I). The case was different in sandy loams with a saline subsoil. The number of bolls per plant were found to be significantly reduced (Table II). In this experiment *desi* cotton (Mollisoni 39) was also included to study the effect of salinity on its growth. The interaction between soils and varieties has come out highly significant as the reduction in boll number had occurred mainly in the case of Mollisoni.

The weight of seed cotton per boll of 4F American cotton plants under saline conditions was found to be significantly lower than weight of seed cotton per boll under normal conditions in light sandy soils as well as in sandy loams (Tables I and II). Thus, bad opening or *tirak* had occurred in saline soils and not on normal soils as the weight of seed cotton per boll was lowered in the former and not in the latter. The case of *desi* was different. No bad opening of bolls is known to occur in *desi* and the measurements of the boll weights under saline and normal conditions have amply borne out this fact (Table II). There was very little difference between the weights of seed cotton per boll in the case of the *desi* plant under saline and normal soils. The reduction in the boll size of *desi* cotton is only 2·14 per cent, while the reduction in 4F is 25·8 per cent. On account of this reason the interaction of soils with varieties on boll size is strongly suggestive. It was thus clear that on saline subsoils the *desis* suffered mainly in the boll number and the Americans mainly in the boll size.

The yields under saline conditions were found to be significantly lower than the yields under normal conditions of soil (Tables I and II). Mollisoni yielded significantly more than the 4F but the interaction between soil and variety was not significant (Table II).

The number of the flowers produced per plant in the 4F American and *desi* plants and the rates of flowering were determined on sandy loam soils. The number of flowers produced per day per unit area of 12 sq. ft. were determined in both the varieties in five plots separately. The 4F plant produced 160·2 flowers per 12 sq. ft. on saline subsoil as compared with 243·8 for normal soil. The *desi* produced 216·6 flowers as compared with 424·4 on normal soil.

The flowering curves for the two varieties on the two soil conditions given in Fig. 8 show that in the case of 4F the rate of flowering dropped on 29 September on saline subsoil, while the maximum production of flowers was continued for another 10 days on normal soils. Similar differences in the flowering rates under two soil conditions were also found in the *desi* variety.

Thus, the depressing effects of salinity in the subsoil are on the total dry matter produced, on the opening of the bolls, i.e. on the maturity of seeds and on yields. The number of bolls per plant is lowered by the presence of salts in the subsoil in the sandy loam soils, but it is not the case with a plant growing on a light sandy soil. The low efficiency of the plants for producing fruiting parts and the immaturity of seeds under saline conditions bring about low yields of seed cotton.

The above-mentioned observations on the growth of cotton plants have been made on soils which are free from salts on the one hand and which are highly saline in the subsoil on the other. The salinity in the subsoil varies and, therefore, the effect on the growth of the plant will not be so high and marked if the soil has medium salinity in the subsoil. When *tirak* occurs on such soils with medium salinity during years of dry and warm weather at the fruiting stage (i.e. in years of cotton failures), the growth of the plant is normal but bad opening of the bolls with immature seeds is caused by the cessation in the growth of the bolls which suffer from a temporary dislocation of their water supply.

The following disturbances in the physiological activities of the plant are produced by the presence of salinity in the subsoil.

The growth of roots is inhibited by the presence of sodium salts. If the salts are in the first foot of the soil the roots of the seedlings cease to grow. An examination of the roots showed that the lateral rootlets died off as soon as they were produced in such saline layers.

A condition of physiological drought results when the subsoil is saline. There is enough moisture from the third foot downwards but it is not available to the plant. The moisture that is present only in the non-saline upper 2 ft. of the soil is available to the plant, but when the upper layers get dried up the plants show symptoms of water starvation. This can be seen from the drooping position of the leaves (Plate XXV, fig. 2). The drooping of leaves was found to occur a week after irrigation during the months of September and October and the leaves did not regain their normal position till the next irrigation. In the month of September the plant bears the maximum leaf area and consequently the water loss from the leaves becomes very high from that stage. The demand for water is thus greatly increased and is not met with from the soils.

Internally the mesophyll cells of the leaves are found in a collapsed condition and the protoplasts have contracted. The mesophyll cells are thus not functioning normally. The new leaves produced at the apices of the stems or the branches remain small. The inter-nodal lengths are shortened and the flowers and bolls on the fruiting branches get crowded at tips on account of the cessation of extension growth.

The reasons for the depressing effects produced, on growth and yields and on the opening of the bolls, of salinity in the subsoil are thus clear. The presence of salinity in the subsoil produces disturbances in the functional activities of the plants due to deleterious effects of sodium salts on the rootlets. A high concentration of salts in the subsoil produces a kind of physiological drought and the water relations of the plants get gradually more and more upset as season advances. The other functional activities of the leaves are adversely affected and the production of dry matter is lessened. The bolls are not able to mature and contain immature seeds with poor quality of lint.

In view of the importance of this relationship between salinity and bad opening established here, it was necessary to test this view by a study of the effects of applications of sodium salts on the growth of plants in normal (non-saline) soils. It would be interesting to know if similar symptoms of *tirak* could be reproduced in a soil which is non-saline, by adding sodium salts.

II. Effects of applications of sodium salts to non-saline (normal) soils on growth and development of tirak

The object of the investigation was twofold. It was at first necessary to establish experimentally that sodium salts were responsible for the development of *tirak* symptoms in the American cotton plants. It was also necessary to know which of the four sodium salts was causing this trouble.

The first few attempts made in the cotton seasons of 1937-38 and 1938-39 to reproduce the symptoms of *tirak* by the applications of sodium salts were unsuccessful. The causes for this lack of success were gradually realized and removed from the later experiments, and, therefore, these early attempts with the results obtained are not described. In the early stages of these attempts enough quantities of salts as they were found to exist under natural conditions were not used. In order to make the subsoil saline, trenches or pits had to be dug up to a depth of 2 or 3 ft. The salts were added in the pits or trenches and they were irrigated after the earth was replaced. The digging thus loosened the earth and increased aeration and, therefore, the growth of the roots was very vigorous in the upper 2 ft. of the soil surface. The result was a very luxuriant plant growth.

The effects of injecting sodium salts into well-grown plants in normal soils were also studied. Different concentrations of each sodium salt were used. The salt solution was injected from one of the branches on the main stem and the total quantity of solution absorbed was recorded. As a result of a large number of injection experiments, it was found that injection of sodium salts produced no effect on the opening of the bolls.

The toxic effect of sodium chloride and sodium carbonate was tested out in 1937-38 in plots of 4F cotton plants grown in normal soils. Sodium chloride at the rate of 1,500 lb. per acre was added on 9 October. In another plot sodium carbonate was spread at the rate of 750 lb. per acre. The salts were applied at the base of each plant. The plots were then irrigated. The leaves showed signs of injury on the eighth day after application and they all drooped and died. The rootlets were killed. The undeveloped bolls dried up, but fully matured bolls (unopened at the time of application) opened normally.

A complex field experiment to study the applications of different salts on the soil surface was laid out in 1938. The salts were applied in March and washed down by irrigation. Three irrigations were given before sowing. It was later found that the quantities of salts added were not adequate to raise the concentrations up to the same levels as found in nature. This was verified by soil analysis. The experiment, therefore, did not yield any information.

In the same year, another experiment was laid out where the salts were added below the surface. Under natural conditions, total concentrations of salts are low in the first 2 ft. of the soil, but they begin to rise from the third foot downwards. Attempts were, therefore, made to reproduce similar trend in concentrations on a normal soil. Sodium chloride and sodium carbonate were the two salts employed, as these two have been known, in the case of other plants, to be most toxic in their effects. The treatments were all combinations of NaCl and Na_2CO_3. The lay-out was randomized block arrangement with six replicates. The size of each plot was 15 ft. × 10 ft.

The quantities of each salt required to raise the concentration of each in each foot of the soil as given below were calculated and used.

TABLE III

Percentage concentration of the sodium salts in different layers

Depth in ft.	Sodium carbonate	Sodium chloride	$NaCl + Na_2CO_3$
1st	0·000	0·055	0·055
2nd	0·025	0·110	0·135
3rd	0·050	0·165	0·215
4th	0·075	0·220	0·295
5th	0·100	0·275	0·375
Total	0·250	0·825	1·075

The earth up to a depth of 4 ft. was removed in 6 in. layers from each plot and heaped separately. The required quantity of each salt for the fifth foot was calculated and added after loosening the soil of the fifth foot. Soil of the last 6 in. of the fourth foot was replaced in the pit and the required quantity of each salt for that layer was weighed, added and was thoroughly mixed with soil. The process was repeated up to the topmost layer. The plots were then irrigated. The crop was sown in 1939-40 cotton season.

A number of observations were made in each plot during the growth of crop. As the plants could not be sampled for dry weights on account of the small size of the plot the weight of sticks and branches was collected from each plot after harvesting.

The drooping of the leaves was found to occur in a majority of plots treated with sodium chloride and the mixture of sodium carbonate and sodium chloride.

The weight of stems and branches per plant, the number of bolls per plant, the weight of seed cotton per boll and the yields were recorded. The yields had to be adjusted for stand by analysis of covariance as there were gaps in the stands in some of the plots and as the total number of plants in each plot was small. The analysis of variance, the means and the significant interaction are given in Table IV.

The depressing effects of sodium salts on weight of stems per plant, yields, boll number and boll weight were clearly visible and these effects were significant. The weight of seed cotton per boll was significantly reduced under these treatments, indicating that these salts had produced immaturity of seeds as they do under natural conditions. Sodium carbonate proved more harmful than sodium chloride in reducing the boll numbers.

The results of yield were statistically analysed after adjusting the yields for stand by the help of analysis of covariance. The regression of yield on plant numbers, for plots treated alike, was found to be 0·0769 after eliminating

differences due to blocks and treatments. The correlation between yield and plant number was 0·6609 and was significant.

TABLE IV

Analysis of variance and mean weight of stems, boll numbers, weight of seed cotton per boll and yields

(Mean squares)

Due to	D. F.	Stems	Boll numbers	Weight of seed cotton per boll	Yield in lb. (adjusted)
Blocks	5	826456	8844	0·0475	0·1376
Chloride	1	6501045**	115926*	0·2072	0·5367*
Carbonate	1	6059145**	256267**	0·3876*	1·03090**
Interaction	1	1288530	33900	0·0376	0·6002*
Error	15	663238	21316	0·0475	0·1116

	Wt. of stems in gm.	Boll number per plot	Wt. of seed cotton in gm. per boll	Yield in lb. (adjusted)
Control	2781	505·9	0·995	1·11
Chloride	1740	366·9	0·809	0·81
Control	2763	539·8	1·029	1·19
Carbonate	1758	333·1	0·775	0·72
S. E. D.	±332·4	±59·6	±0·088	±0·147

Yield differential response ± 0·208

	Chloride		Carbonate	
	Presence	Absence	Presence	Absence
Chloride	..	..	+0·02	—0·62
Carbonate	—0·15	—0·79	..	..

* Significant at 5 per cent level **Significant at 1 per cent level

The two treatments also significantly depressed the yield. The interaction chloride × carbonate was significant and positive indicating that chloride had proved less harmful in presence of carbonates than in their absence.

The experiment clearly indicated that the growth and yields were reduced by the presence of sodium salts. The opening of bolls was bad and the seeds remained immature when the salts were added. Thus, *tirak* symptoms were reproduced by additions of sodium salts. In the above experiment the doses of salts added were rather heavy and they proved very toxic and the plants were very stunted in size.

Another experiment to study the effect of sodium salts on the growth and development of *tirak* was, therefore, laid out in the cotton season of 1939-40, using smaller concentrations than those used in the above-mentioned experiment. The concentrations of salts used were such that when distributed over a depth of 4 ft. they would be nearly the same as those generally found in *tirak* patches. These patches generally contained chlorides, bicarbonates and sulphates, while sodium carbonate was not present in all cases. Sodium sulphate was not included as previous experience had shown that it was not having any effect on the plants in concentrations in which it occurred in such soils. The experiment was, therefore, designed to study the effects of sodium carbonate and sodium bicarbonate (quality) at three levels ; 0, single dose, double dose ; in combination with three levels, i.e. 0, single dose, double dose, of sodium chloride. The combination carbonate and bicarbonate was automatically excluded. There were thus 18 treatments comprising the following combinations :—

	(0)	(0)
(Sodium bicarbonate)	(Single dose)	(Sodium chloride I)
(Sodium carbonate)	(Double dose)	(Sodium chloride II)
Quality	Quantity	Chloride

All treatments were completely randomized in each block. Three replicates were provided. Plot size was 1/81 acre.

The quantity of each salt to be added to the soil was calculated so as to give the required concentration for one acre-foot of soil. The percentage concentration of a single dose of chloride was kept equal to the percentage concentration of a double dose of carbonate or bicarbonate. The actual quantity of each salt in each dose and its percentage concentration in one acre-foot of soil are given in Table V.

For calculating the percentage concentrations for acre-foot of the soil, it was taken that a cubic foot of soil weighed 100 lb. and consequently an acre-foot would weigh 4·4 million pounds. When these quantities of salts were added to the soil they would be washed down by irrigation at least to a depth of 4 ft. Thus, the concentrations of these salts would fall on account of their distribution over a greater volume of soil than one acre-foot. The soil of the field where this experiment was laid out was normal (without salinity). Salts were added behind a deep furrow-turning plough on 16-18 March and the plots were irrigated three times at regular intervals before sowing of cottons so that they may be washed down to lower layers and may not injure the seedlings. The crop was sown by the middle of May.

TABLE V

Actual quantities of sodium salts added and their percentage concentrations expressed on salt and acid radical basis per acre-foot of soil

	Actual quantity added lb. per acre	Per cent concentration of the salt per acre-foot of soil	Per cent concentration of acid radical per acre
Sodium chloride (single) . .	8000	0·182	0·109
Do. (double) .	16000	0·362	0·218
Sodium bicarbonate (single) .	3336	0·076	0·054
Do. (double) .	6672	0·151	0·109
Sodium carbonate (single) .	4288	0·097	0·054
Do. (double) .	8576	0·195	0·109

TABLE VI

Analysis of variance for the vegetative parts

Due to	D. F.	Dry weights		Height		Leaf area		Inter-nodal lengths	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F
Blocks .	2	3261		147·75		206·63		0·1136	
Treatments .	14	11952	3·162**	363·44	5·801**	439·31	3·491**	0·2234	7·522**
Error .	37	3780		62·65		125·83		0·0297	
Quality † .	1	26136	6·914*	871·23	13·906**	727·20	5·779*	0·5304	17·859**
Quantity ‡ .	2	4835		L = 267·32 Q = 16·26	4·267*	444·98	3·536*	0·1261	4·246*
Chloride .	2	47718	12·622**	1549·36	24·730**	1412·14	11·222**	1·0057	33·862**
Quality × Quantity .	1	121		13·81		961·00	7·637**	0·0117	
Quality × Chloride .	2	§L = 17822 Q = 1901	4·715**	*L = 361·15 Q = 41·56	5·765*	124·00		L = 0·1617 Q = 0·0284	5·444*
Quantity × Chloride .	4	448		52·34		118·46		0·0095	
Quantity × Quality × Chloride .	2	7231		104·40		12·96		0·0469	

* Significant at 5 per cent level ** Significant at 1 per cent level

† Quality = (Sodium bicarbonate); (Sodium carbonate)

‡ Quantity = (0); (Single dose); (Double dose)

§ L = Linear Q = Quadratic

TABLE VII

Analysis of variance for fruiting parts

Due to	D. F.	Boll dry matter		Boll number		Weight of seed cotton per boll		Yield	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F
Blocks .	2	804		381·01		0·3328		104123	
Treatments.	14	344		158·01		0·2499		644110	2·101*
Error .	37	345		105·58		0·1515		306545	
Quality† .	1	140		35·56		0·2664		312	
Quantity‡ .	2	242		198·01		0·0826		237591	
Chloride .	2	§L=1521 Q= 43	4·409*	L=247·16 Q=837·80	7·935**	L=0·8515 Q=0·0610	5·620*	2277628	7·430**
Quality × . Quantity .	1	38		33·89		0·3612		1401066	4·571*
Quality × . Chloride .	2	L=1504 Q= 207	4·359*	51·27		L=0·0108 Q=0·7656	5·053*	402244	
Quantity × . Chloride .	4	187		74·11		0·1312		78648	
Quality × . Quantity × . Chloride .	2	65		131·39		0·2465		733326	

* Significant at 5 per cent level ** Significant at 1 per cent level

† Quality = (Sodium bicarbonate); (Sodium carbonate) ‡ Quantity = (0); (Single dose); (Double dose);

§ L = Linear Q = Quadratic

As it was undertaken to study the effects of sodium salts on the growth of plants and development of *tirak*, the following data were recorded. The total dry weight per plant and dry weights of its different organs like stems, leaves and flowers plus bolls were determined on 18 November. A five-plant sample was taken from each plot. The height and node numbers of the main axis were determined for five plants on each plot at 10-day intervals. The total leaf area on the main axis was also determined at 10-day intervals by a method to be described later The rate of flowering (five plants from each plot) was also measured during the flowering phase. The number of bolls per plant and the weight of seed cotton per boll were determined in two separate samples of five plants each. The final yield of each plot was also determined.

The design of the experiment was such that all the data recorded, as mentioned above, could be statistically analysed by the method of analysis of variance. The variances and their ratios for each treatment and for the combinations are given for each determination in Tables VI and VII. It will be seen that the treatments as a whole were significant, indicating that different treatments had behaved differently, and a further analysis of the data was worth while.

In the following discussion of the treatment effects on the vegetative and reproductive parts of the plants, stress will only be laid on the effects of those treatments which have come out significant.

Dry weight per plant

A summary table for dry weight per plant showing the effects of different treatments is given in Table VIII. The main effects with the standard error and the significant interactions are also given. There was a gradual depression in dry weight under chloride with its increasing concentrations. The same was the case with carbonate, but no such depressing effect was found with bicarbonate. The generalized effects of chloride and quality were therefore significant and negative. The behaviour of carbonate and bicarbonate was different in presence of chloride. The depressing effect of carbonate increased with increasing concentrations of chloride but that was not the case to the same extent in the case of bicarbonate. The interaction quality $\times$ chloride was therefore negative and significant.

Dry weights of stems and leaves per plant

The dry weights of stems or leaves per plant behaved similarly as the total dry weight per plant, and these results are, therefore, not discussed here.

Dry matter of bolls per plant

Chloride depressed significantly the boll dry matter produced per plant with increasing concentrations, while no such effect was found either with carbonate or bicarbonate (Table VIII). Thus, the depression in total dry weight per plant under carbonate was mainly caused by a depression in the vegetative organs of the plant. Thus, chlorides decreased the dry weights of vegetative as well as the fruiting parts, while carbonate depressed only the former. The percentage of boll material produced by the plants under carbonate was therefore higher than under chloride. The effects of carbonate and bicarbonate again differed in the presence of chloride. The production of boll material under carbonate decreased with increasing concentrations of chloride, but no such decrease was noticeable under bicarbonate in the presence of chloride at different levels. The interaction quality $\times$ chloride was therefore significant.

Heights per plant

On account of the small size of the plots it was not possible to draw periodic samples of plants for the determination of dry weights at regular intervals to study the effects of these treatments on the growth of plants. The growth in extension was therefore studied at 10-day intervals for the whole life-cycle of the plant. Figs. 9 and 10 give the absolute heights at each stage of growth under chloride and quality. The depression in height occurred under chloride from the early seedling stage, while a similar depression in height was found under carbonate as compared with bicarbonate,

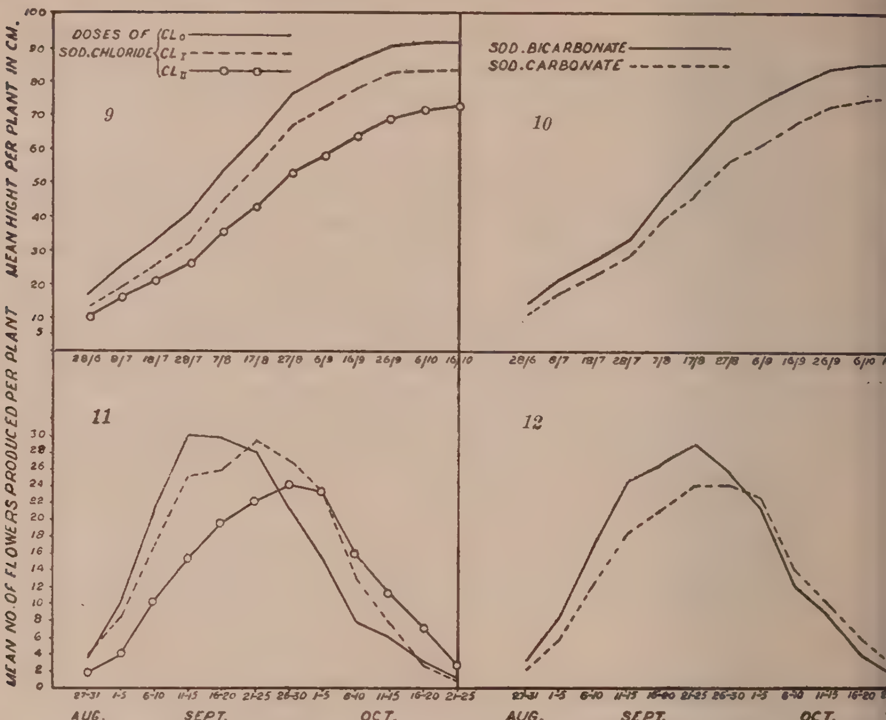

FIG. 9. Mean height in cm. per plant in 4F in presence of three levels of sodium chloride
FIG. 10. Mean height in cm. per plant in 4F in presence of sodium carbonate and sodium bicarbonate
FIG. 11. Rates of flowering in 4F in presence of three levels of sodium chloride
FIG. 12. Rates of flowering in 4F in presence of sodium carbonate and sodium bicarbonate

The final heights are given in Table VIII. There was a progressive decline in extension growth with increasing concentrations of chloride or carbonate. There was no such decline in the case of bicarbonate. The main effects of chloride, quality and quantity were therefore significant. The interaction quality $\times$ chloride was also significant, indicating a differential behaviour of carbonate and bicarbonate in presence of chloride. Thus, the growth in extension and dry weights were similarly affected by these salts.

Number of nodes per plant

The number of nodes per plant was not affected by any one of the treatments (Table IX). This fact suggested that sodium salts did not in any way affect the uptake of nitrogen from the soil.

Inter-nodal lengths

As the heights were depressed while the node numbers remained unaffected, the depression in extension growth was caused by a shortening in the inter-nodal lengths as shown in Table IX. The depressing effects of

TABLE VIII

Effect of salts on total dry weight, dry matter of bolls and height

	Total dry matter in gm. per plant						Dry matter of bolls in gm. per plant						Height in cm. per plant					
	Control	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean	Control	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean	Control	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean
Control	352	337	332	346	303	337	73	76	77	82	88	78	93·2	91·2	92·7	90·1	86·6	91·1
NaCl I	317	341	256	248	282	294	73	79	65	84	66	73	85·9	88·2	82·3	76·2	80·7	83·2
NaCl II	243	278	302	189	153	234	61	77	81	61	51	65	76·8	77·7	81·1	65·0	55·6	72·2
Mean	304	319	296	261	246	288	69	77	74	76	68	72	85·3	85·7	85·4	77·1	74·3	82·1

Mean dry matter per plant S. E. D. = ±20·5 Mean boll matter S. E. D. = ±6·190 Mean height per plant S. E. D. = ±2·63

Chloride			Quality		Quantity		
0	Chl. I	Chl. II	Bic.	Carb.	0	Single dose	Double dose
337·1	293·8	234·6	307·7	2[illegible]3·8	304·1	290·1	271·4

Chloride			Quality		Quantity		
0	Chl. I	Chl. II	Bic.	Carb.	0	Single dose	Double dose
79	73	66	75·5	72	69	76·5	71

Chloride			Quality		Quantity		
0	Chl. I	Chl. II	Bic.	Carb.	0	Single dose	Double dose
91·14	83·17	72·17	85·52	75·69	85·27	81·38	79·82

Interaction

	0	Chl. I	Chl. II
Na_2CO_3 . . .	325·0	265·3	171·1
$NaHCO_3$ . . .	334·6	298·6	289·8
Diff. . . .	—9·6	—33·3	—118·7

S. E. D. = ±35·49

Interaction

	0	Chl. I	Chl. II
Na_2CO_3 . .	85·0	75·1	56·0
$NaCHO_3$.	76·5	72·3	79·1
Diff. . .	+8·5	+2·8	—23·1

S. E. D. = ±10·72

Interaction

	0	Chl. I	Chl. II
Na_2CO_3 . .	88·33	78·43	60·30
$NaHCO_3$.	91·93	85·23	79·41
Diff. . . .	—3·60	—6·80	—19·11

S. E. D. = ±4·566

chloride, quality and quantity were significant as in the case of heights. Similarly, interaction of quality with chloride is significant, indicating differential behaviour of carbonate with bicarbonate in presence of sodium chloride. The shortening of internodes indicated a deficiency in water supply. It was found by Crowther [1934] in Sudan and recently confirmed in the Punjab that heavy watering increased the inter-nodal lengths, while nitrogen increased both the node numbers and the inter-nodal lengths. The presence of sodium salts therefore appeared to interfere with the absorption of water from the soil by exerting deleterious effects on the roots. This was an additional confirmation of the view that salinity in the subsoil was causing a disturbance in the moisture relations of the cotton plants at the fruiting stage.

Total leaf area on the main axis

The total leaf area on the main axis of the plant was determined by a special method which did away with the necessity of detaching the leaves from the plant. The removal of leaves would be necessary for planimetric measurements of the leaf areas. A 4F leaf resembles more or less an equilateral triangle whose area is given by the formula $h^2/\sqrt{3}$. The value of h was determined in the case of the leaf by measuring the distance from the base of the lamina to the apex. The differences in the values obtained by this method and by the planimetric method were found to be ± 5 per cent. This method will be described in more detail in a separate paper. The results of leaf area are given in Table IX. The depressing effects of chloride, quality and quantity were found to be significant as in the case of heights. Sodium chloride and sodium carbonate decreased the leaf area in presence of high concentrations of these salts. Sodium bicarbonate produced no such depressing effect and the interaction quality $\times$ quantity was significant.

It may be mentioned here that different samples of plants were used for determining dry weights, heights and leaf area. The depressing effects of sodium chloride and sodium carbonate discussed above could therefore be regarded as real effects.

Number of flowers per plant

The record of daily flower production was maintained for five plants in each of 54 plots. Five-day totals of flowers produced per plant during the flowering phase are given in Figs. 11 and 12 under chloride and quality. The sodium salts had a delaying influence on the crop arrival. Harris [1929] working on Egyptian cottons found a similar delay in the crop arrival in presence of high salinity in the soil. Sodium chloride and sodium carbonate depressed the flower production, the depression being greater in presence of the latter salts than in the former. Sodium bicarbonate had no effect. The effects of chloride and quality were significant (Table IX).

Number of bolls per plant

Sodium chloride slightly increased the boll number under low concentration, while it depressed the boll number under high concentration (Table X) and therefore the quadratic response of chloride on boll numbers came out to be significant (Table VII). As the flower and the boll numbers

TABLE IX

Effect of sodium salts on node number, leaf area, flower production andinter—nodal lengths

	Node numbers per plant						Total leaf area on the main axis in sq. cm.						Total number of flowers per plant						Inter-nodal lengths in cm.					
	Control	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean	Control	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean	Control	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean	Conrol	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean
Control	36·	35·4	37·2	36·1	37·1	3	2480	2594	2722	2770	2469	2586	171	179	191	188	159	178	2·58	2·57	2·49	2·49	2·33	2·51
NaCl I	35·8	35·9	35·2	34·6	35·6	35·5	2673	2768	2626	2718	2252	2618	179	187	197	163	195	183	2·40	2·45	2·34	2·20	2·26	2·34
NaCl II	35·7	35·6	36·5	34·2	34·2	35·3	2294	2420	2465	2373	1932	2297	178	150	173	156	115	158	2·15	2·19	2·23	1·90	1·62	2·04
Mean	35·9	35·6	36·3	35·0	35·6	35·7	2482	2594	2604	2620	2217	2500	176	172	187	169	156	172	2·38	2·40	2·35	2·20	2·07	2·30

No mean effects are significant   Mean leaf area on main axis S. E. D. = ±74·8   Mean number of flowers S. E. D. = ±7·71   Mean inter-nodal length S. E. D. = ±0·0574

Chloride			Quality		Quantity			Chloride			Quality		Quantity			Chloride			Quality		Quantity		
0	Chl. I	Chl. II	Bic.	Carb.	0	Single dose	Double dose	0	Chl. I	Chl. II	Bic.	Carb.	0	Single dose	Double dose	0	Chl. I	Chl. II	Bic.	Carb.	0	Single dose	Double dose
2586	2619	2297	2599	2419	2482	2607	2411	176·7	183·4	158·3	179·7	162·7	176·1	170·6	171·7	2·51	2·34	2·04	2·38	2·13	2·38	2·30	2·21

Interaction

	Single dose	Double dose
Na_2CO_3	2621	2218
$NaHCO_3$	2594	2604
Diff.	+27	—386

S. E. D. = ±105·7

Interaction

	0	Chl. I	Chl. II
Na_2CO_3	2·41	2·23	1·76
$NaHCO_3$	2·53	2·39	2·21
Diff.	—0·12	—0·16	—0·45

S. E. D. = ±0·0995

were both depressed in a double dose of sodium chloride the setting percentage was not affected. This was not the case with sodium carbonate. Sodium carbonate decreased the flower production, but the number of bolls per plant did not show similar depression. The setting percentage must therefore be high in presence of sodium carbonate.

Weight of seed cotton per boll

Sodium chloride definitely decreased the boll weight due to immaturity of seeds and the linear response of chloride on weight of *kapas* (seed cotton) per boll was significant. This was an important finding that sodium chloride alone produced immaturity of seeds and consequently bad opening or *tirak*. The effect of sodium carbonate on the weight of seed cotton per boll was quite opposite. It increased the weight of *kapas* per boll though the effect of quality was not significant. The interaction of quality with chloride was significant (Table X).

Yield

Sodium chloride depressed the yields under high concentrations and the effect of chloride was significant (Table X). Sodium bicarbonate showed a stimulating effect in high concentrations, while sodium carbonate showed a similar effect in low concentrations. The depressing effect of sodium chloride on yields was due to a decrease in boll number as well as decrease in boll weight (i.e. decrease in weight of seed cotton per boll). The stimulating effect of sodium carbonate in low concentrations on yields was due to an increase in the boll weight and a small increase in boll number.

The interaction quality × quantity was found to be significant as sodium bicarbonate in high concentrations increased the yields, while sodium carbonate in low concentrations increased and in high concentrations decreased the yields.

Discussion

The symptoms of *tirak* were reproduced by applications of sodium chloride and sodium carbonate separately and in combination with one another. The doses of salts used in the first experiment were very large and the injurious effect of these salts was great on the plants. In the second experiment smaller doses of these salts were used and the differential action of each salt on the vegetative growth of the plant as well as its fruiting parts was visible. The findings of the second experiment are therefore briefly discussed.

Sodium chloride in low concentrations depressed to a small extent vegetative growth but had no effect on the fruiting parts and yields. The same salt under high concentrations exercised a very great depressing effect on its vegetative and fruiting parts. The total dry weight per plant, height per plant, leaf area, yields and boll size were significantly lowered in presence of sodium chloride when applied at the rate of 16,000 lb. per acre. The weight of seed cotton per boll was greatly reduced indicating immaturity of seeds and consequently the chief symptom of *tirak* was reproduced in presence of sodium chloride.

TABLE X

Effect of sodium salts on boll number, boll weight and final weight of Kapas

	Total number of bolls per plant						Weight of seed cotton in gm. per boll						Final yields in gm. per plot (1/186 acre)					
	Control	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean	Control	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean	Control	$NaHCO_3$ I	$NaHCO_3$ II	Na_2CO_3 I	Na_2CO_3 II	Mean
Control	34·1	44·4	38·1	37·5	37·6	37·6	1·22	0·99	0·99	1·25	1·32	1·16	2248	2188	2133	2472	2493	2297
NaCl I	38·2	42·2	42·8	50·3	38·5	41·7	1·02	1·15	1·32	1·35	0·79	1·10	2107	2297	2911	2830	1576	2305
NaCl II	34·2	34·1	36·0	32·7	32·4	33·9	0·83	0·81	0·96	1·15	1·10	0·95	1576	1551	1866	1900	1639	1685
Mean	35·5	40·2	38·9	40·2	36·2	37·7	1·02	0·98	1·09	1·25	1·07	1·07	1977	2012	2303	2401	1903	20[illegible]

Mean boll numbers S. E. D. = $\pm 2{\cdot}42$ Mean weight of seed cotton per boll S. E. D. = $\pm 0{\cdot}0937$ Mean yield per plot S. E. D. = $\pm 184{\cdot}5$

Chloride			Quality		Quantity			Chloride			Quality		Quantity			Chloride			Quality		Quantity		
0	Chl. I	Chl. II	Bic.	Carb.	0	Single dose	Double dose	0	Chl. I	Chl. II	Bic.	Carb.	0	Single dose	Double dose	0	Chl. I	Chl. II	Bic.	Carb.	0	Single dose	Double dose
37·6	41·7	33·9	39·5	38·3	35·5	40·2	37·5	1·16	1·10	0·95	1·04	1·16	1·02	1·12	1·08	2297	2305	1685	2157	2151	1976	2206	2103

Interaction				Interaction		
	0	Chl. I	Chl. II		Single dose	Double dose
Na_2CO_3	1·289	1·066	1·126	Na_2CO_3	2400	1903
$NaHCO_3$	0·991	1·236	0·889	$NaHCO_3$	2012	2302
Diff.	+0·298	—0·170	+0·237	Diff.	+388	—400

S. E. D. = $\pm 0{\cdot}159$ S. E. D. = $\pm 184{\cdot}5$

Sodium carbonate in low concentrations (4,288 lb. per acre) showed some depressing effect on the vegetative growth, but it was found to have a small stimulating effect on the production of boll material and consequently the yields. The most noticeable feature was the increase in boll size. High concentrations of the same salt (8,576 lb. per acre) depressed greatly the vegetative growth resulting in low dry weights, heights and leaf area. The yields were lowered as compared with the yields obtained under low concentrations of this salt. It may also be stated that the toxic effect of carbonate depends mainly on the clay content. In light sandy soils this salt when present is found to produce *tirak*.

Both the salts decreased the inter-nodal lengths but had no effect on node numbers. The decrease in the inter-nodal length indicated a deficiency of water as cotton plants are found to produce smaller internodes in absence of adequate waterings.

Sodium bicarbonate had no effect on the growth of the plant either under low or high concentrations except for an indication of a stimulating effect on yields.

The effect on plant's development of sodium carbonate and of sodium bicarbonate was different in presence of sodium chloride. The depressing effect of carbonate on plant's growth increased in presence of sodium chloride, so much so, that the dry weights, heights, boll material and yields were greatly reduced under high concentrations of the two salts. The case was different with sodium bicarbonate, where this salt in high concentration appeared to decrease the depressing effects of high concentrations of sodium chloride. It was on account of this differential behaviour of the two salts in the presence of chloride that the interaction of quality with chloride was found to be significant on dry weight, height and boll material.

Thus, sodium chloride depressed both the vegetative growth and yields. It also produced immaturity of seeds and thus caused bad opening. Carbonate decreased the vegetative growth but had a stimulating effect on fruiting parts, especially under low concentrations. Bicarbonate under high concentrations appeared to decrease the depressing effect on yields of high concentrations of sodium chloride.

It is already reported [Dastur and Samant, 1942] that sodium salts are present in abnormal quantities in the Punjab soils where *tirak* occurs and they are one of the causes of *tirak* of cottons. The sodium salts found in the soils where *tirak* occurs are chloride, bicarbonate and sulphate of which the last two are not found to be toxic in the concentrations in which they are generally found. Sodium carbonate is not generally present in such soil types. From the results discussed above, it therefore appears that sodium chloride is mainly responsible, by its deleterious effects on the absorbing organs of the plants, for the development of *tirak* in the American cotton plants in the Punjab. The presence of carbonate may aggravate *tirak* symptoms while the presence of bicarbonate may lessen it, depending on the relative proportions of the two or the three salts present and their actual concentrations. In addition, other factors of the soil like the physical structure and quantity of calcium in soluble and exchangeable form and the seasonal

conditions may also affect, one way or the other, the course of events leading to *tirak* conditions.

The investigation reported in this paper has thus yielded a direct experimental evidence that salinity in the subsoil is causing *tirak* in the Punjab-American cottons.

SUMMARY

The investigation is divided into two sections. Section I includes the study of the growth of the American cotton plants under known conditions of soil. These are : (1) normal soils where *tirak* did not occur, (2) sandy loams with a saline subsoil where *tirak* was known to occur and (3) light sandy soil with a saline subsoil where *tirak* was also known to occur. Section II deals with a study of the effects of artificial applications of sodium salts to a field with non-saline normal land on the growth of the American cotton plants. It was attempted to obtain experimental evidence to support the view that presence of sodium salts in abnormal amounts in the subsoil was causing *tirak* in the Punjab-American cottons.

The growth of cottons was depressed in presence of salinity in the subsoil as compared with the growth made by plants on normal soils. The depression in growth was greater in sandy loams than in light sandy soils, the subsoil being saline in both cases. The number of bolls per plant were greatly reduced in the former but not in the latter type of land. The bad opening of the bolls as measured by the weight of seed cotton per boll occurred in all soils with saline subsoils and the yields were lowered. These effects of salinity on the growth and yields were found to be significantly by depressing when compared with the growth and yields of plants on normal soils.

Similar depressing effects on growth and yields were reproduced by applications of sodium salts to a known normal soil. There were, however, some differences in the effects produced on the cotton plants by each kind of sodium salt. Sodium chloride in high concentrations (16,000 lb. per acre) depressed the vegetative growth as well as the yields. The bad opening of the bolls was produced in presence of this salt. Thus *tirak* was reproduced in presence of sodium chloride. Sodium carbonate, though depressed the vegetative growth, was found to have a stimulating effect on boll size and yields when used in low concentrations (4,281 lb. per acre). This salt in double concentration depressed further the vegetative growth and showed less stimulating effect on the fruiting parts than what was found with low concentrations.

Sodium chloride and sodium carbonate had no effect on node numbers but decreased the inter-nodal lengths, indicating that they caused a disturbance in the water supply of the plants.

Sodium bicarbonate either under low or high concentrations showed no effect either on growth or yield.

In the presence of carbonate the depressing effect of chloride was found to increase, while in the presence of bicarbonate the depressing effect of chloride on growth and yields was found to decrease.

Sodium chloride is present in abnormal amounts in the soils where *tirak* is found to occur, while sodium carbonate is not found to be always present

in such soils. As bicarbonates and sulphates at the concentrations in which they are present in the soil were not found to show deleterious effects on plant's growth, sodium chloride appeared to be mainly responsible for development of *tirak* in the American cottons. The presence of other sodium salts may either aggravate or lessen *tirak*, depending on the relative proportions of these salts and their actual concentrations in the subsoil. In addition, other properties of the soil and the seasonal conditions may also affect one way or the other the development of *tirak* on this type of soils with saline subsoils.

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REFERENCES

Ahi, S. M. and Powers, W. L. (1938). Salt tolerance of plant at different temperatures. *Plant Physiol.* **13,** 767-789

Breazeale, J. F. (1927). A study of toxicity of salines that occur in black alkali soils. *Univ. Arizona Tech. Bull.* **14**

Crowther, F. (1934). Studies in growth analysis of the cotton plant under irrigation in the Sudan. I. The effects of different combinations of nitrogen applications and water supply. *Ann. Bot.* **48,** 377-913

Dastur, R. H. and Samant, K. M. (1942). Studies in the periodic partial failures of the Punjab-American cottons in the Punjab. V. Physical and chemical properties of the soils associated with *tirak* Bad openings. *Ind. J. agric. Sci.* **12**

Harris, F. S. (1915). Effect of alkali salts in soils on the germination and growth of crops. *J. agric. Res.* **5,** 1-83

——— (1920). *Soils Alkali.* John Wiley and Sons, New York

Harris, F. S. and Pittman, D. W. (1918). Soil factors affecting the toxicity of alkali. *J. agric. Res.* **15,** 287-319

Harris, J. A. (1929). The correlation between the soil salinity and flowering date in cotton. *J. agric. Res.* **38,** 109-12

Headley, F. B. Curtis, E. W. and Scofield, C. S. (1916). Effect on plant growth of sodium salts in the soil. *J. agric. Res.* **6,** 857

Hibbard, P. L. (1925). Alkali soils-origin, examination and management. *Calif. agric. Expt. Sta. Circ.* **292**

Hilgard, E. W. (1906). *Soils,* pp. 465-85. Macmillan & Co., New York

Joseph, A. F. (1925). Alkali investigation in Sudan. *J. agric. Sci.* **15,** 407

Kearney, T. R. and Scofield, C. S. (1936). *U. S. Dept. Agric. Circ.* **404**

Neidig, R. E. and Magnuson, N. P. (1924). Alkali studies, I. Tolerance of wheat for alkali in Idaho soil. *Soil Sci.* **18,** 449-67

Theron, J. J. (1937). Alkali and irrigation studies with citrus trees in the Sunday's River Valley. *Univ. Pretoria Public Series* **1,** (*Agric.*) 40

Voelcker, J. A. (1916). Sodium salts on wheat. *J. Roy. agric. Soc.* **77,** 262

VARIATIONS IN THE MEASURABLE CHARACTERS OF COTTON FIBRES

IV. VARIATIONS WITH THE AGE OF THE PLANT

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VARIATIONS in the lint characters caused by (1) the position of the seed in the lock, (2) change of place of growth and (3) different manurial treatments, were dealt with in previous publications [Iyengar, 1941, 2, 1 and 3]. The present work pertains to the variations observed with advancement in the age of the plant. That variations do exist among the pickings, is a known fact. Commercially, the earlier pickings fetch a higher price than the later ones. The quality of the end pickings is usually inferior. Balls [1915] has observed that ' differences between the pickings is a matter of accident—excluding boll-worm—and not of direct and necessary causation '. Continuing he states ' there are more chances of unfavourable accidents late in the season than in the beginning of the season, but most of them can be avoided '. This remark is in connection with the Egyptian cotton crop, where irrigation facilities are well under control. In the case of Indian cottons, most of which are rain-grown, such avoidance of accidents is out of question.

In the particular case studied by Balls [1915] he observed the earliest bolls to be weak, but among the other pickings he found a rise and fall in quality. In another place also he [Balls, 1930] observed a similar systematic swing in the quality. Zaitsev and Gasteva [1925] picked different ' cycles ' separately and found that the seed weight, lint weight, ginning percentage, ribbon width and fibre strength decreased with the advance of age. The length and the number of convolutions per unit length, however, were found to increase. They attributed the increase in length to the longer maturation period of the later formed bolls and the reduction in other characters to the poorer nutrition in the later age. Hawkins and Serviss [1930] found that the ' time of season during which cotton fibres develop affects the rate of fibre-wall thickening greatly but does not influence the rate of fibre growth in length to any appreciable extent until late in the season '. Ayyar and Rao [1930] found some significant differences in fibre length between the pickings but no regular trend. Venkataraman [1930] on the other hand, observed a systematic decrease in seed weight, lint weight and lint length with advance of picking. Barre and Armstrong [1930] found that earlier maturing bolls had appreciably longer fibres. Armstrong and Bennet [1933] observed a reduction in the length of fibres in the last picking. Sen [1934] found a reduction in the fibre weight and maturity with the advance of the season. The number of fibres per seed was also found to be considerably greater in the earlier pickings. Mayo [1938] did not find any variation in the maturity of the fibres among the different pickings. It will be seen from

the foregoing that various trends of differences have been observed varying according to strain, place and season. In the present work the variations caused by the age of the plant in the cottons of South India are recorded. The effect of application of mineral manures during the middle of the plants' life on the quality of the final picking is also dealt with.

Material and methods

The material for the first of the three studies described in the present paper, consisted of seven pure strains of cotton grown at the various Agricultural Research Stations of the Madras presidency. As the variation with the age of the plant was the object of the study, special precautions were taken to reduce variations caused by the position of the seed in the lock and locular composition. Arrangements were made to pick the cottons weekly from bolls having definite number of locks and to collect locks containing definite number of seeds. At the time of sampling, seeds of definite position in each lock alone were chosen for comparative study. The details relating to the different strains are furnished in Table I.

TABLE I

Particulars of sampling and picking

Particulars	*G. herbaceum*		*G. arboreum*				*G. hirsutum*
	2465	H 1	X 14	171	Karunganni C 7	Karunganni C 7	Co 2 irrigated
Place of growth	Coimbatore	Hagari	[illegible]	[illegible]	Coimbatore	Koilpatti	Coimbatore
Year of growth	1930-31	1933-34	1933-34	1933-34	1930-31	1933-34	[illegible]
Bolls selected	3-locked	3-locked	3-locked	3-locked	3-locked	3-locked	[illegible]
Locks selected	7-seeded	7-seeded	6-seeded	7-seeded	7-seeded	7-seeded	[illegible]
Position of seed used for study	4th	4th	4th	4th	4th	4th	4th & 5th
Dates of weekly pickings							
I	5-3-31	2-2-34	23-2-34	14-3-34	10-3-31	5-3-34	[illegible]
II	12-3-31	9-2-34	2-3-34	21-3-34	17-3-31	12-3-34	[illegible]
III	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
IV	26-3-31	23-2-34	15-3-34	4-4-34	31-3-31	26-3-34	9-3-3?
V	2-4-31	2-3-34	22-3-34	11-4-34	7-4-31	2-4-34	[illegible]
VI	9-4-31	9-3-34	29-3-34	18-4-34	14-4-31	9-4-34	[illegible]
VII	16-4-31	16-3-34	5-4-34	...	21-4-31	16-4-34	[illegible]
VIII	[illegible]	[illegible]	[illegible]		[illegible]	23-4-34	5-4-3?
IX	30-4-31	...	...	...	...	30-4-34	
X	7-5-31	...				...	

It might, however, be stated that by this method of sampling, though the main effects of each of the individual factors are eliminated, their interaction would still continue to persist. It is also possible that some other interactions of these factors on the weekly pickings may also get removed. For example, in the later age, probably more bolls with less number of locules and less number of seeds per lock are generally produced in Madras presidency. The method of sampling adopted here excludes such variability.

The characters studied are furnished in Table II. Convolutions and ribbon width could be determined in three cottons only on account of its time consuming nature.

TABLE II

Variation of characters among weekly pickings

Order of picking	Seed weight (mg.)							Lint weight (mg.)						
	2405	H 1	N 14	171	C 7 CBE	C 7 KPT	Co 2	2405	H 1	N 14	171	C 7 CBE	C 7 KPT	Co 2
I	79	71	51	55	52	56	140	26	28	16	20	26	28	76
II	72	72	53	53	51	56	146	26	29	26	18	26	27	80
III	72	73	52	55	49	55	147	26	33	15	18	24	27	76
IV	65	73	51	56	48	51	140	24	33	15	18	24	26	74
V	64	67	51	55	48	50	137	24	31	16	16	21	26	74
VI	58	64	49	56	48	50	133	20	29	16	16	21	24	70
VII	58	60	46	...	48	48	131	22	25	14	...	21	22	68
VIII	55	55	45	...	50	48	126	20	25	13	...	23	22	63
IX	53	...	...	...	...	44	...	20	...	...	...	...	18	...
X	53	...	...	...	...	...	...	20	...	...	...	...	...	...
	Ginning percentage							Mean length in inch						
I	25	29	24	26	34	34	35	0·97	0·95	0·94	0·88	0·89	0·86	1·03
II	26	29	23	26	34	33	35	0·93	0·99	0·93	0·85	0·87	0·91	1·04
III	26	31	23	25	33	33	34	0·92	0·93	0·94	0·82	0·86	0·88	1·03
IV	27	31	23	24	33	34	34	0·87	0·95	0·93	0·83	0·88	0·86	1·03
V	27	32	24	22	31	34	35	0·86	0·89	0·93	0·86	0·86	0·89	1·03
VI	26	31	24	22	30	32	34	...*	0·86	0·92	0·87	0·89	0·90	1·01
VII	27	30	24	...	30	32	34	0·78	0·81	0·88	...	0·92	0·88	0·95
VIII	27	32	23	...	31	31	34	0·77	0·79	0·87	...	...*	0·92	0·94
IX	28	...	...	...	...	29	...	0·80	...	...	...	...	0·90	...
X	27	...	...	...	...	...	...	0·80	...	...	...	...	...	...
	Weight per cm. in 10^{-6} gm.							Standard fibre weight in 10^{-6} gm.						
I	2·15	2·10	1·96	2·00	2·05	1·92	1·92†	1·75	1·82	1·72	1·77	2·05	1·83	2·17
II	2·28	1·99	2·05	1·98	2·11	1·88	1·87	1·98	1·76	1·76	1·74	2·16	1·83	2·03
III	2·45	2·29	1·90	2·09	2·00	1·91	1·87	2·12	2·00	1·66	1·84	2·13	1·81	2·10
IV	2·44	2·21	1·91	2·05	2·11	2·01	1·88	2·12	1·94	1·65	1·79	2·07	1·87	2·14
V	2·34	2·18	1·94	1·90	1·85	1·94	1·81	2·03	1·92	1·68	1·68	1·90	1·75	2·15
VI	...*	2·10	2·00	1·92	1·90	1·90	1·77	...*	1·84	1·72	1·72	1·93	1·86	2·12
VII	2·51	2·01	2·02	...	1·93	1·88	1·85	2·14	1·80	1·72	...	1·89	1·90	2·11
VIII	2·47	2·05	1·97	[illegible]	...*	1·74	2·04	2·10	1·82	1·70	...	...*	1·77	2·31
IX	2·47	...	[illegible]	...	...	[illegible]	[illegible]	2·10	[illegible]	[illegible]	...	...	1·78	...
X	2·62	...	[illegible]	[illegible]	[illegible]	...	[illegible]	[illegible]	[illegible]	[illegible]	...	...	...	...

* The fibre characters for these samples were not determined as the samples indicated anomalous lint weights

† The fibre weight for this cotton was determined by cutting one centimetre lengths as that method was in vogue in 1930 when this sample was tested

TABLE II—*contd.*

Order of picking	2405	H 1	N 14	171	C 7 CBE	C 7 KPT	Co 2	2405	H 1	N 14	171	C 7 CBE	C 7 KPT	Co 2
	No. of fibres per seed in thousands							Fibre strength in gm.						
I	4·83	5·62	3·38	4·44	5·69	6·78	15·2	4·9	3·5	6·0	5·4	4·6	4·0	4·1†
II	4·75	5·82	3·23	4·30	5·57	6·25	16·2	4·7	4·0	6·6	4·9	4·3	4·0	3·7
III	4·48	6·12	3·39	4·08	5·62	6·27	15·6	4·8	4·1	6·1	5·1	4·7	4·7	4·1
IV	4·43	6·16	3·34	4·13	4·25	6·00	15·1	4·2	4·5	6·2	5·0	4·5	4·4	3·6
V	4·65	6·35	3·38	3·86	5·22	5·90	15·7	4·0	4·3	6·2	4·7	4·1	4·6	3·6
VI	...	6·29	3·38	3·73	4·83	5·52	15·4	...	4·1	5·8	4·9	4·4	4·3	3·4
VII	4·35	6·08	3·18	...	4·57	5·26	15·2	3·8	3·7	5·4	...	4·1	4·0	3·5
VIII	4·18	6·18	3·06	...	...	5·28	13·0	3·6	3·5	5·2	...	...*	4·0	3·4
IX	4·09	...	...	...	...	4·68	...	3·5	...	...	...	...	3·6	...
X	3·64	...	...	...	...	...	...	3·7	...	...	...	...	...	...
	Mature fibres percentage							Immature fibres percentage						
I	94	93	90	90	77	76	57	2	2	2	3	16	6	20
II	93	89	95	90	72	73	61	3	3	1	3	16	8	17
III	93	91	91	90	69	77	54	3	2	2	3	20	6	22
IV	93	91	93	91	72	81	56	3	2	2	2	17	5	22
V	94	89	94	90	74	85	53	3	2	2	3	17	3	25
VI	...*	89	93	88	71	75	52	...*	2	2	4	16	11	25
VII	96	85	95	...	77	72	56	2	2	1	...	13	14	23
VIII	96	88	94	...	...	71	57	2	1	2	...	...*	13	21
IX	96	...	...	...	...	64	...	1	...	...	...	...	...	...
X	95	...	...	...	...	...	...	2	...	...	...	...	...	...

	No. of convolutions per cm.									Mean ribbon width (μ)						
		S. E.							S. E.							
I	13	0·600	...	...	...	13	...	58	1·95	16·5	...	...	...	15·2	...	15·5
II	14	0·624	...	...	...	16	...	60	1·86	15·8	...	...	...	...	...	14·5
III	12	0·602	...	...	...	13	...	47	1·84	16·1	...	...	...	...	...	15·2
IV	10	0·498	...	...	...	13	...	39	1·25	16·6	...	...	...	15·2	...	15·2
V	8	0·480	...	...	...	14	...	35	1·48	16·2	...	...	...	...	...	14·9
VI	...	...*	...	...	...	13	...	30	1·24	...	...	...	...	...	...	15·2
VII	8	0·425	...	...	...	12	...	22	1·12	16·0	...	...	...	15·0	...	14·2
VIII	8	0·423	...	...	...	...*	...	20	0·98	16·0	...	...	...	...	...	14·9
IX	7	0·396	...	...	...	...	...	...	...	16·2	...	...	...	...	...	...
X	7	0·312	...	...	...	...	...	...	...	15·9	...	...	...	...	...	...

* The fibre characters for these samples were not determined as the samples indicated anomalous lint weights

† Standard errors are not recorded in the table for want of space. The error ranges from 0·103 to 0·176. Roughl a difference of 0·5 gm. may be taken as statistically significant

In the second study Co 2 grown in the summer season under irrigation at Srivilliputhur was utilised. In this case two methods of sampling were made, one being the method described above and the other taking of samples from the balance of the pickings left after the collection of the first type of samples. This was done with the object of studying how the results obtained by the special method of sampling agree with or differ from those obtained from representative samples of the bulk picking.

For the third study Karunganni C 7 grown in randomised plots was utilized. The details of the experiment are given along with the results. In this case also the special method of sampling described above was adopted.

The samples were examined in the following manner. The mean length was determined by the use of Balls sorter and the mean fibre weight (except in one case in which fibres cut to 1 cm. length were weighed) by weighing whole fibres, as followed at the Indian Central Cotton Committee Laboratory [Ahmad, 1933]. The maturity of the fibres was determined by using Clegg's [1932] method for the earlier cottons, and later on, the slide invented by Gulati and Ahmad [1935] was used. O'Neill's' hair tester as modified by Mann and Peirce [1926] was used similarly, until the strength tester of Sukthankar, Ahmad and Navkal [1939] was obtained. The mean ribbon width [Barritt, 1930] was calculated by measuring the maximum as well as the minimum, ribbon-width at 10 places nearly equally spaced along the length of the whole fibre. The convolutions were determined by counting the total number of them over the entire length of the fibre and dividing it by the length.

Results

Seven strains

The results are recorded in Table II. It may be mentioned that they could not be analysed by the method of analysis of variance owing to the fact that the number of pickings, places of growth and seasons varied in the different cottons. The significance of the differences cannot, therefore, be assessed with the aid of the critical difference. The general trends of variation alone are considered. The data of each strain are dealt with separately. The six rain-grown strains are considered first and the solitary irrigated strain Co 2 is described later.

Seed weight.—For both the *herbaceum* strains 2405 and H 1, the reduction, with age appears to be the rule ; for the latter cotton, however, the variation is not considerable among the first four pickings. Coming to the *arboreums* it will be seen that for N 14 the seed weight decreases in the later pickings after a fairly constant value in the earlier pickings. For 171 the variation is not significant. So also is it for Karunganni C 7 (Coimbatore), but for the same cotton grown at Koilpatti the reduction with age from beginning to end is fairly definite.

Lint weight.—In all the cottons decrease with age in this character appears to be fairly consistant. For H 1 there appears to be rise from the first picking to the third or fourth picking before the fall commences. The sixth picking of 2405 and the last of Karunganni C 7 (Coimbatore) appear to record anomalous weights, which will be considered later on. The variation for N 14 is not considerable.

Ginning percentage.—Ginning percentage does not appear to vary for both the strains of *G. herbaceum*. Among the *arboreums*, N 14 and Karunganni C 7 (Koilpatti) show no variation except in the last picking where the value is smaller. For the same cotton grown at Coimbatore the later four pickings record lower figures than the earlier four. For 171, however, the ginning percentage appears to decline gradually with age.

Mean fibre length.—For the two *herbaceums* the length appears to decrease gradually with age ; for H 1, however, it rises from the first to the second before decreasing. No definite variation is apparent among the *arboreums* except that the last pickings of N 14 and the middle ones of 171 record smaller figures.

Zaitsev and Gasteva [1925], found an increase in length with advance of age, which they attributed to the longer maturation period of the later formed bolls, and as a consequence the longer lengthening phase of the fibre. In the present finding, the opposite is the case, the later formed bolls having a shorter maturation period and lengthening phase. If longer lengthening phase corresponds to longer length, the present results and those of Zaitsev and Gasteva may be said to agree. But this relationship is not strictly true as can be seen from another finding of the writer [Iyengar, 1941, 1].

Fibre weight per cm.—Fibre weight does not appear to exhibit definite variation. The last pickings of Karunganni C 7 may be said to record lower values at both the places. The conspicuously high value for the last pickings of 2405 is rather puzzling.

Standard fibre weight.—This property also does not appear to indicate any definite variation.

Number of fibres per seed.—Of the *herbaceums*, 2405 indicates a higher value in the first two pickings, a lesser but fairly constant one in the middle pickings and still smaller value in the end pickings. H 1, however, ha a smaller value in the first two pickings and is steady later on. Among the *arboreums* N 14 records a lower figure in the last two pickings. For the other three cottons the number of fibres may be said to decrease gradually with the advance of age. It may be mentioned that Sen [1934] observed a considerably higher number of fibres in the first picking.

Maturity.—Maturity appears to be fairly constant in all cases, except in Karunganni C 7 (Koilpatti) where the later pickings record lower values.

Fibre strength.—For 2405 the strength is definitely less for the later pickings. The first and last pickings of H 1 have definitely lower strength than the rest. 171 and Karunganni C 7 may be said to exhibit small variability. But the latter cotton at Koilpatti appears to have greater strength in the middle pickings and N 14 lesser strength in the last pickings.

Convolutions per cm.—In the case of 2405 the convolutions decrease with advance of age from 14 to 7, a decrease of 50 per cent of the higher value ; many differences between pickings are significant. In the case of Karunganni C 7, the variation is not considerable. It will be seen that in the case of Co 2 also this character decreases from 60 to 20, a fall of over 60 per cent, with the advance of age. Unfortunately for want of time, the determination of this character in the other cottons could not be done.

Contrary to the above finding Zaitsev and Gasteva found the convolutions to increase with age. In their case the atmospheric temperature

decreased with the advance of season, while in the present it increased. Putting the two together, it looks probable, that higher temperature is associated with production of lesser number of convolutions per unit length. A study of the convolutions in samples similar to those in the previous work [Iyengar, 1941, 1] may throw light on this point.

Mean ribbon width.—Mean ribbon width does not indicate any variation. Zaitsev and Gasteva found the maximum ribbon width to derease with age. In the present case the maximum ribbon width also exhibits no variation.

The variation in the irrigated strain Co 2 may now be considered. The seed weight and lint weight fall with age after a preliminary rise from the first to the second picking. The ginning percentage, however, indicates no variation. Mean fibre length is less in the last pickings. Fibre weight per cm. and standard fibre weight are found to be greater in the last picking which cannot be explained. Number of fibres per seed is constant in all the pickings except the last in which it is less. Variation in the fibre strength, maturity percentages and mean ribbon width are not large. The convolutions, as already stated, decrease considerably with advance of age. It will be seen from the foregoing that the trends of variation for this cotton are not distinctly different from those of the other rain-grown cottons. Irrigation, therefore, does not appear to have produced any marked change on the variation considered here.

To sum up, the six characters, viz. seed weight, lint weight, mean-fibre length, number of fibres per seed, fibre strength and number of convolutions per cm. may be said to exhibit variations in the different pickings, the variations in the other characters being small. Generally speaking, the end pickings indicate reduced values for the characters listed above. In some cases, however, a consistant reduction with age is apparent. The reduction in the number of convolutions with age is considerable indeed in two cottons. These findings may be said to agree, in a general way, with those of the other workers, except those of Zaitsev and Gasteva in the case of fibre length and convolutions, an explanation for which has been given.

As all the cottons studied, except Co 2, are rain-grown, the influence of rainfall on the quality of the picking may now be considered. The distribution of rainfall shows that most of it ends by November after which upto April there is hardly any rain. Hence the influence of the rainfall immediately before the weekly picking cannot be ascertained. But in one case its influence appears to be fairly clear. That is, the rainfall of 1·32 in. at Coimbatore at the end of the first week of April 1931, after a long period of draught from the middle of November 1930. This heavy shower appears to be responsible for the anomalous increase in the seed weight and lint weight in the last picking (28th April 1931) of Karunganni C 7 (Coimbatore) and also for the increase in the lint weight for the seventh picking (16th April 1931) of 2405.

Co 2 grown at Srivilliputhur

It may be recalled, that two methods of sampling were adopted in the enquiry. In the one, seeds from the fourth and fifth positions of nine-seeded locks alone were sampled for study, the whole of the remaining picking being taken for the second. It may be mentioned that attempts were first made

to collect weekly pickings from all the four replications available. Later on, it was found that the quantity of the sample in the individual replication was not sufficient for test in some of the pickings. The produce of all the replications was, therefore, mixed in all cases except in picking of 25 August 1937 for which the replications were kept separate in order to have an idea of the variation among the replications. The data obtained according to both the methods of sampling are given in Table III.

TABLE III

Variation of characters among weekly pickings

(Co 2, Srivilliputhur)

Order of picking	Date of picking	Length in inches		Fibre weight per cm. in (10^{-6} gm.)		Standard fibre weight (10^{-6} gm.)		Maturity per cent	
		A	B	A	B	A	B	A	B
I	28-7-37	1·02	...	1·69	...	1·70	...	68—9	...
II	4-8-37	1·02	...	1·74	...	1·69	...	73—7	...
III	11-8-37	1·02	1·10	1·72	1·58	1·68	1·62	72—7	68—14
IV	18-8-37	1·01	1·06	1·67	1·58	1·63	1·61	77—6	70—13
V	25-8-37	0·99	1·04	1·68	1·64	1·65	1·73	72—8	64—14
VI	1-9-37	0·97	1·04	1·74	1·61	1·69	1·61	74—8	68—8
VII	8-9-37	0·99	1·04	1·69	1·55	1·69	1·62	69—9	64—13
V R 1	25-8-37	1·01	1·03	1·67	1·61	1·58	1·73	77—6	62—16
V R 2	25-8-37	0·98	1·04	1·72	1·65	1·69	1·76	74—10	61—14
V R 3	25-8-37	0·98	1·04	1·69	1·69	1·67	1·76	70—7	66—14
V R 4	*	0·98	1·06	1·66	1·62	1·66	1·67	68—8	66—12
								Mature fibres	Immature fibres
Mean difference (A—B)		—0·0588		0·0812		—0·011		6·5	—5·25
S. E.		0·00687		0·01808		0·0279		1·70	0·995
t		8·55		4·48		0·394		3·83	5·27
Remarks		Highly significant		Highly significant		Not significant		Highly significant	Highly significant

A = Whole picking ; B = 4th and 5th seeds of nine-seeded locks

It will be seen that the variations between the replications are small and within the limits of error. Further, the variations between the pickings are equally low except in the case of fibre length, where a marked tendency for a reduction in length in the later pickings is manifest. Both the sets of results point to the same conclusion.

When the actual values obtained by the two methods are compared, it is found that the mean fibre length according to the special method of sampling is in all cases greater than that according to the random samples, while the fibre weight and maturity for the former are distinctly less. The increase in length for the special sample may be accounted for by the fact that this was carefully delinted by hand, while the other was ginned in a gin. The lower maturity may be result of the fact, found in a previous study [Iyengar,

1941, 2], that the maturity of fibres for the fourth and fifth seeds of nine-seeded locks (51·34) is less than the average for the whole lock (56·24). The lower maturity is responsible for the lower fibre weight per cm. as is shown by the non-significance of the difference in the standard fibre weight.

TABLE IV

Variation among weekly pickings

Manured and unmanured

Date of picking	Seedweight (mg.)		Lint weight (mg.)		Ginning (percentage)		Mature fibres (per cent)		Immature fibres (per cent)	
	Man.	Unman.	Man.	Unman.	Man.	Unman.	Man.	Unman.	Man.	Unman.
23-3-38	54·2	52·7	21·5	20·5	28·5	28·2	63·8	60·3	15·5	17·2
30-3-38	49·8	49·0	20·2	20·5	28·8	29·3	64·8	66·3	14·8	12·7
7-4-38	44·5	44·3	18·0	17·5	28·8	28·3	66·7	61·5	13·3	14·5
14-4-38	41·5	41·7	16·0	16·3	28·0	28·2	63·0	63·5	14·3	13·7
21-4-38	39·0	38·8	13·7	15·0	26·7	28·0	62·7	62·8	13·2	14·7
27-4-38	38·8	40·2*	16·2*	14·7	29·8	26·8	56·7	68·8	13·8	9·2

Property	Variance due to	Degree of freedom	Sum of squares	Mean square	Critical diff. $P=0 \cdot 05$
Seed weight (mg.)	Total	71	2583·88	...	Between pickings within treatment
	Manure	1	0·69	0·69	
	Pickings	5	2020·30	404·06**	3·48
	Int. M X P	5	13·72	2·74	
	Residual	60	549·17	9·15	
Lint weight (mg.)	Total	71	592·00	...	
	Manure	1	0·50	0·50	
	Pickings	5	437·83	67·57**	1·74
	Int. M X P	5	16·00	33·20	
	Residual	60	137·67	2·29	
Ginning percentage	Total	71	193·88	...	
	Manure	1	0·35	0·35	
	Pickings	5	34·13	6·83**	1·59
	Int. M X P	5	44·90	8·98**	
	Residual	60	114·50	1·91	
Mature fibres (per cent)	Total	71	3691·50	...	
	Manure	1	6·72	6·72	
	Pickings	5	88·00	13·60	8·36
	Int. M X P	5	427·78	85·56	
	Residual	60	3169·00	52·82	
Immature fibres (per cent)	Total	71	1192·32	...	
	Manure	1	5·01	5·01	
	Pickings	5	140·57	28·11	4·58
	Int. M X P	5	94·91	18·98	
	Residual	60	951·83	15·86	

**Significant for 1 per cent point

Effect of Manure on the later pickings

It has been seen above that the seed weight, lint weight and maturity get reduced in the later pickings of Karunganni C 7 (Koilpatti). It was suggested by Dr Nazir Ahmad to see whether the application of manure in the middle of the plants' life would off-set this deterioration. Accordingly Karunganni C7 was grown in randomised plots replicated six times. Ammonium sulphate and superphosphate were applied to the specified plots early in January. Weekly pickings for the replications were examined. The work was carried out at the Cotton Breeding Station, Coimbatore for want of facilities at Koilpatti. As the crop had to be manured it was grown under irrigation. The results have been analysed by the variance method. Both the results and analysis of variance are recorded in Table IV.

It will be seen that (1) the effect of manure is negligible, (2) the variance between weekly pickings is highly significant for seed weight, lint weight and ginning percentage but not for maturity, (3) the seed weight and lint weight indicate a tendency to decrease gradually with the advance of age (the two high values marked with asterisks may probably be due to sampling error, the sample being very small in the last picking) and (4) the maturity has not deteriorated in the last pickings in both the manured and unmanured treatments. It should be stated, however, in the present case the pickings ended by 7th April, while in the previous case they continued upto 30th April.

Conclusion

Seed weight, lint weight, mean fibre length, number of convolutions per unit length, number of fibres per seed and fibre strength indicate variations among the pickings. Generally speaking a reduction in these characters is noticed in the last pickings, though in some cases there exist trends of reduction even from the earlier stages. The fall in the number of convolutions per cm. is very conspicuous in two cottons.

Though the actual values of the characters for the special method of sampling is distinctly different from those got for a random sample, the trend of variation among the pickings shewn by either set of values is the same in both cases.

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References

Ahmad, N. (1933). *Indian Cent. Cot. Com. Tech. Lab., Tech. Bull. Series A.* **25**
Armstrong, G. M. and Bennett, C. C. (1933). *J. agric. Res.* **47**, 467-74
Ayyar, V. R. and Rao, C. J. (1930). *Agric. J. India,* **25**, 44-5
Balls, W. L. (1915). *Development and Properties of Raw Cotton.* A. & C. Black, London
——— (1930). *Min. agric. Egypt. Tech. Sci. Service Bull.* **101**
Barritt, N. W. (1930). *Emp. Cot. Grow. Rev.* **7**, 19-29

Barre, H. W. and Armstrong, G. M. (1930). *South Carolina Station Report*
Clegg, G. G. (1932). *J. Text. Inst.* **23**, T 35-T 54
Gulati, A. N. and Ahmad, N. (1935). *Indian Cent. Cot. Com. Tech. Lab. Tech. Bull. Series B.* No. **20**
Hawkins, R. S. and Serviss, G. H. (1930). *J. agric. Res.* **40**, 10-29
Iyengar, R. L. N. (1941, 1). *Second Conference on Cotton Growing Problems in India, Report*, 145-6
——— (1941, 2). *Indian J. agric. Sci.* **11**, 703-735
——— (1941, 3). *Indian J. agric. Sci.* **11**, 866-875
Mann, J. C. and Pierce, F. T. (1926). *J. Text. Inst.* **17**, T 84
Mayo, J. K. (1938). *Emp. Cot. Grow. Rev. III Conference Report*, p. 164
Sen, K. R. (1934). *Indian J. agric. Sci.* **4**, 295-319
Sukthankar, S. S. Ahmad, N. and Navkal, H. (1939). *Indian Cent. Cot. Com. Tech. Lab. Tech. Bull. Series B.* No. **26**
Venkataraman, S. N. (1930). *Agric. J. India.* **25**, 193-4
Zaitsev, G. S. and Gasteva, A. M. (1925). *Reports from Turkestan Plant Breeding Station Tashkent* (Empire Cotton Growing Corporation Publication)

PROPERTIES OF SUB-FRACTIONS OF HYDROGEN CLAY PREPARED FROM INDIAN SOILS, II*

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(With three text-figures)

In the previous part [Mukherjee, Mitra and Chakravorty, 1942 ; also, Mitra and Chakravorty, 1939] results obtained with nine sub-fractions prepared from a red lateritic soil from Dacca (Bengal) and a black soil from Akola (Central Provinces) have been discussed. The different sub-fractions from any one of these soils gave the same type of titration curves. The base-exchange capacity (b. e. c.) calculated from the titration curves, however, rapidly increased with diminishing particle size. Also, the finer the fraction the greater was the percentage of sesquioxides and the smaller that of silica in the ignited clays. The centrifugal force developed by the 'bucket type' centrifuge used for this work was, however, not sufficient for the separation of very fine fractions. This has now been done with the aid of a Sharples supercentrifuge following Ayre's method as described by Whitt and Baver [1937]. The clay fraction has been divided into a larger number of sub-fractions having particle sizes within narrower limits, thus permitting a closer examination of the variations in properties with the particle size. Results obtained with 27 sub-fractions prepared from five soils have been presented in this paper. Particulars regarding the soils and the sub-fractions are given in Table I.

The same density† of the different fractions and a spherical symmetry of the particles have been assumed in calculating the particle size (and the specific surface). These assumptions are somewhat arbitrary. The particles are more often anisometric [Marshall, 1930]. And sub-fractions having markedly different chemical compositions may not have the same density.

* The results given in this paper have been taken from the published Annual Reports for 1938-41 on the working of a scheme of research into the 'Properties of Colloid Soil Constituents' financed by the Imperial Council of Agricultural Research, India, and directed by Dr J. N. Mukherjee

** Senior Assistant Soil Chemist under the above scheme

† The densities in toluene of the five sub-fractions from the Latekujan soil have been measured and values between 2·55 and 2·61 obtained. These fractions have more or less the same chemical composition (Table II)

TABLE I

Particulars of soils and sub-fractions

Description of soil	Reference No. of sub-fraction	Reference No. of corresponding hydrogen clay	Limiting equivalent spherical diameters in microns
1. Black cotton soil from Satara district, Bombay, collected from a depth of 0-6 in. (Lab. No. 25)	1	Satara F-1	1·0 and 2·0
	2	,, F-2	0·50 ,, 1·0
	3	,, F-3	0·20 ,, 0·50
	4	,, F-4	0·10 ,, 0·20
	5	,, F-5	0·05 ,, 0·10
	6	,, F-6	$<$0·05
2. Neutral black calcareous soil from Government farm at Padegaon, Type B, collected from a depth of 0-12 in. (Lab. No. 46)	1	Padegaon B-1	0·20 and 2·0
	2	,, B-2	0·10 ,, 0·20
	3	,, B-3	0·04 ,, 0·10
	4	,, B-4	0·02 ,, 0·04
	5	,, B-5	0·015 ,, 0·02
	6	,, B-6	$<$0·015
3. High land acid soil on old alluvium from Government farm at Latekujan, Assam, collected from a depth of 0-6 in. (Lab. No. 53)	1	Latekujan F-1	0·12 and 2·0
	2	,, F-2	0·084 ,, 0·12
	3	,, F-3	0·058 ,, 0·084
	4	,, F-4	0·038 ,, 0·058
	5	,, F-5	$<$0·038
4. High land acid soil from Government farm at Oating, Assam, collected from a depth of 0-6 in. (Lab. No. 55)	1	Oating F-1	0·10 and 2·0
	2	,, F-2	0·04 ,, 0·10
	3	,, F-3	0·02 ,, 0·04
	4	,, F-4	$<$0·02
5. High land yellow calcareous soil from Government farm at Krishnagar, Bengal, collected from a depth of 0-6 in. (Lab. No. 16-A)	1	Krishnagar F-1	1·0 and 2·0
	2	,, F-2	0·50 ,, 1·0
	3	,, F-3	0·20 ,, 0·50
	4	,, F-4	0·10 ,, 0·20
	5	,, F-5	0·05 ,, 0·10
	6	,, F-6	$<$0·05

The variations in composition have to be kept in view in comparing the base exchange capacities and the nature of titration curves with bases of the different fractions.

EXPERIMENTAL

The methods used for the preparation of the hydrogen clays, their chemical analysis and electrometric titration with bases have been described in the previous part [Mukherjee, Mitra and Chakravorty, 1942]. The specific surfaces of the different sub-fractions from the Latekujan soil have been calculated from the amount of methylene blue adsorbed per gm. The concentration of the dye before and after adsorption has been determined with the aid of a spectrophotometer.

RESULTS

The percentages of SiO_2, Al_2O_3 and Fe_2O_3 in the ignited hydrogen clays the silica-sesquioxide ratios, and the base exchange capacities* (b. e. c.)

* Calculated at the inflexion point of titration curves with NaOH

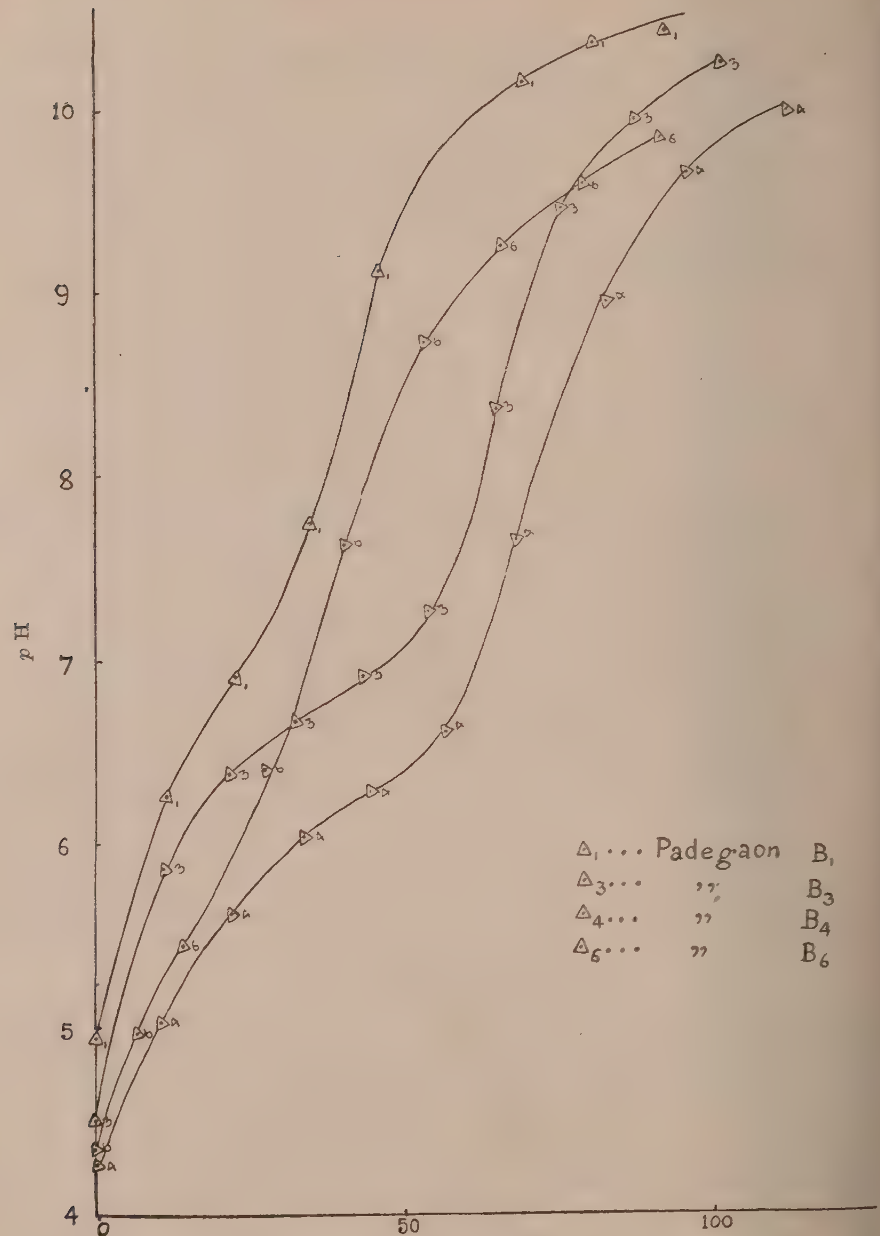


FIG. 1. Titration curves with NaOH of four sub-fractions from Padegaon soil

per gm. on the oven-dried basis are given in Table II. Fig. 1 shows the titra-
tion curves with NaOH of four out of the six sub-fractions from the Padegao

l. They all reveal a weak monobasic acid character, a feature also shown the other two fractions and the sub-fractions previously studied [Mukherjee, tra and Chakravorty, 1942]. The same family of curves is also obtained titrating the sub-fractions from the Satara and Krishnagar soils. The

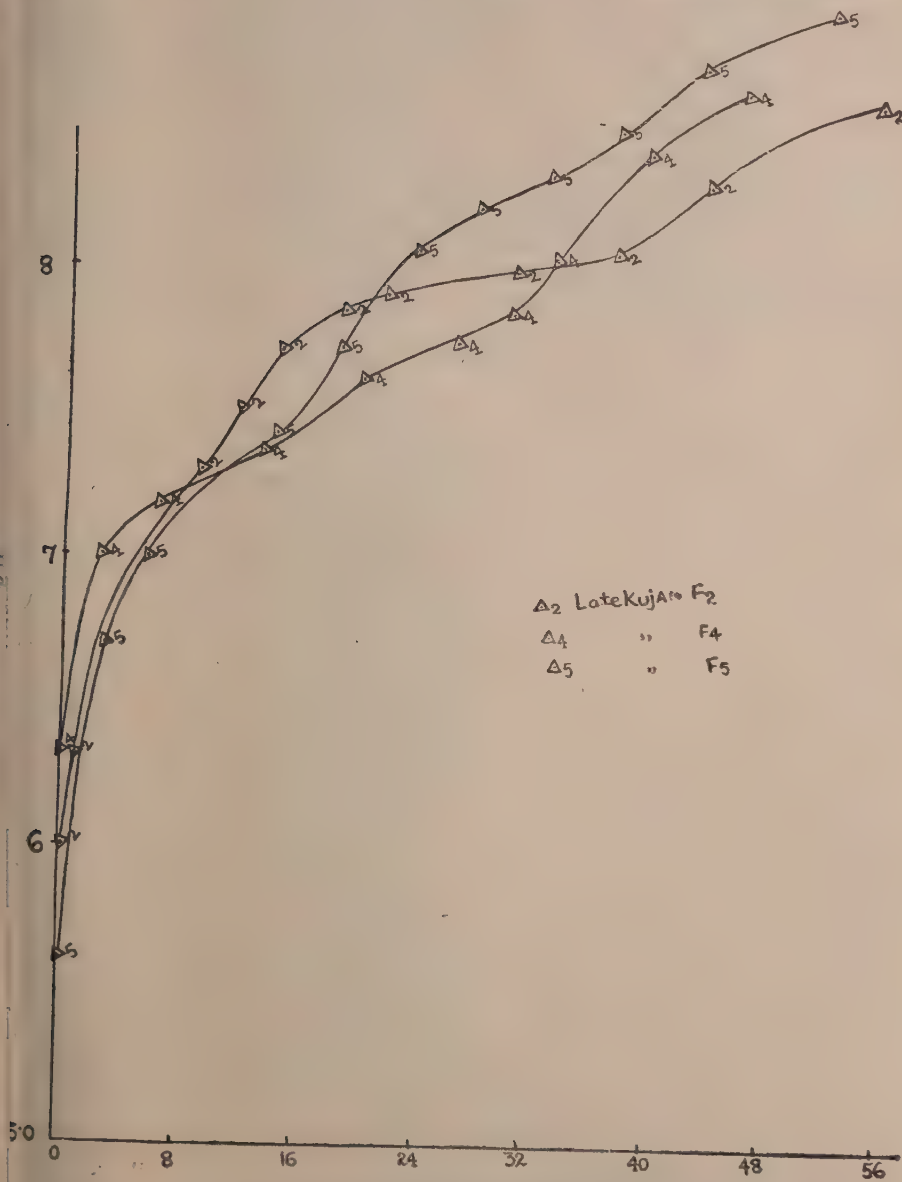
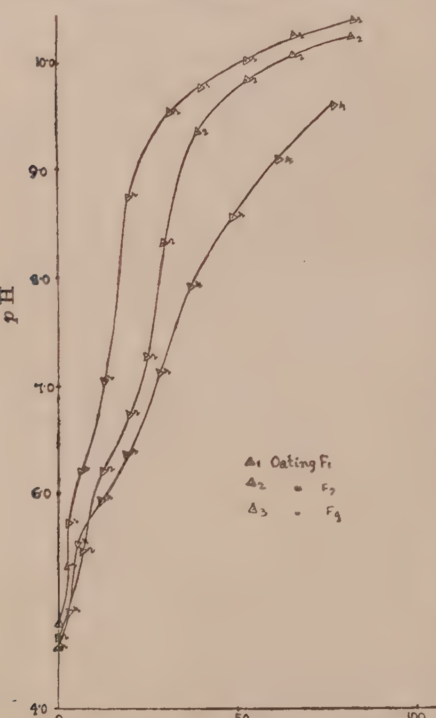


FIG. 2. Titration cur ves of three faactions from Latekujan soil

titration curves of three fractions from the Latekujan soil are shown in Fig. 2. All five fractions from this soil show a weak dibasic acid character. Fig. 3 shows the titration curves of three sub-fractions from the Oating soil. They have a strong dibasic acid character.

The results given in Table II and the variations in the properties of the sub-fractions summarized in Table III reveal the following general trends :—(*a*) The base-exchange capacity usually increases with diminishing particle size; (*b*)this increase is regular either when the chemical composition does not change to any marked extent as in the case of the sub-fractions from the Latekujan and Krishnagar soils or when it changes in a regular manner as observed with the sub-fractions from the Oating soil and the sub-fractions previously studied [Mukherjee, Mitra and Chakravorty, 1942] ; (*c*) when the chemical composition of any one of the fractions steps out of some regular variation in composition with the particle size, the base-exchange capacity also shows a departure from an otherwise regular variation. A case in point is the finest sub-fraction from either of the two black soils. Fraction 2 from the Latekujan soil constitutes another example.



M.e. of NaOH per 100 gm. of colloid

FIG. 3. Titration curves of three sub-fractions from the Oating soil

The following points are also worthy of note :—

(*a*) The percentages of SiO_2 and Al_2O_3 vary with the particle size in opposite senses in the two black soils. As already indicated, the sixth (finest) fraction from both these soils behaves quite differently from the others. It has a much smaller base-exchange capacity than the coarser fractions.* Further, the form of the titration curve of Padegaon B-6 is somewhat different compared with the other members of the Padegaon series;

(*b*) The two acid soils from Assam also differ from each other in the manner in which chemical differentiation takes place along with the mechanical division of the particles. While the sub-fractions from the Latekujan soil have an almost uniform chemical composition, marked variations are observed in the case of the members of the Oating series. Further, the two series give different types of curves ;

* With the exception of fraction 1 from the Satara soil

(*c*) The percentages of SiO_2, Al_2O_3 and Fe_2O_3 in the ignited hydrogen clays seldom add up to 100 ; in most cases, the sum is much lower than 100. The ignited hydrogen clays apparently contain other constituents, e.g. Mg, K, Mn and Ti in a non-exchangeable form ;

(*d*) The base-exchange capacity usually increases, while the silica-sesquioxide ratio decreases. On the other hand, an increase in the base-exchange capacity of entire clay fractions with this ratio is generally observed [Mitra, 1940 ; Mattson, 1931].

TABLE II

Percentages of SiO_2, Al_2O_3 and Fe_2O_3, silica-sesquioxide ratios and the b. e. c. per gm. of the hydrogen clays

Soil	Reference No. of sub-fraction	Chemical composition on the ignited basis				B. e. c. in m. e. NaOH per 100 gm. of over-dried material
		SiO_2 (per cent)	Al_2O_3 (per cent)	Fe_2O_3 (per cent)	$\frac{SiO_2}{R_2O_3}$	
Black cotton soil from Satara . .	1	60·3	13·7	24·9	3·45	54·0 (8·4)*
	2	57·2	19·7	22·5	2·84	68·0 (7·2)
	3	59·6	22·3	19·2	2·92	81·0 (7·6)
	4	56·7	23·4	21·0	2·61	96·0 (7·5)
	5	55·1	24·2	19·6	2·54	97·5 (7·9)
	6	60·0	17·0	22·3	3·25	57·0 (7·8)
Black soil from Padegaon . .	1	59·3	19·8	12·8	3·61	46·5 (7·9)
	2	56·3	21·7	17·0	2·94	59·5 (7·6)
	3	59·5	21·6	14·5	3·38	63·0 (8·0)
	4	64·5	18·0	11·4	4·44	63·0 (7·2)
	5	66·7	17·5	11·0	4·63	70·0 (8·3)
	6	60·0	26·8	10·5	3·05	40·0 (7·5)
Acid soil from Latekujan Farm .	1	55·2	22·9	15·7	2·84	9·0 (6·9); 20·0 (8·4).
	2	52·8	22·7	15·5	2·74	10·0 (7·4); 39·0 (8·1).
	3	54·1	22·2	15·7	2·84	16·5 (7·7); 31·0 (8·0).
	4	55·8	26·3	14·2	2·67	17·0 (7·6); 34·0 (8·0).
	5	57·2	24·1	14·7	2·89	18·0 (7·6); 36·0 (8·5).
Acid soil from Oating Farm . .	1	53·8	31·5	10·9	2·33	14·4 (7·3)
	2	48·6	38·5	11·8	1·80	24·5 (7·3)
	3	45·3	41·6	13·5	1·53	Not determined
	4	43·7	31·6	21·5	1·44	25·0 (6·8)
Calcareous soil from Krishnagar .	1	52·1	27·9	11·9	2·46	8·0 (7·9)
	2	49·8	27·3	12·4	2·39	11·0 (8·3)
	3	50·0	29·7	11·8	2·27	Not determined
	4	49·4	27·5	13·2	2·44	29·0 (7·6)
	5	50·2	25·6	14·5	2·48	43·5 (7·2)
	6	50·5	26·8	11·3	2·51	72·0 (7·3)

* The figures in brackets denote the *p*H at the inflexion point of titration curves

TABLE III

Variations in the properties of sub-fractions with the particle size

Sub-fractions from	Variations with diminishing particle size in				
	SiO_2 (per cent)	Al_2O_3 (per cent)	Fe_2O_3 (per cent)	Base-exchange capacity.	Form of titration curves
1. Black cotton soil from Satara	Decreases up to fraction 5 ignoring fraction 3; then increases	Increases up to fraction 5; then decreases	Decreases up to fraction 5; then increases	Increases up to fraction 6 which gives a much smaller value than the next 4 coarser fractions	No marked variation
2. Black soil from Padegaon	Increases up to fraction 5 ignoring fraction 2; then decreases	Decreases up to fraction 5 ignoring fraction 1; then markedly increases	Decreases ignoring fraction 1	Increases up to fraction 5; fraction 6 gives the lowest value	No marked variation with the possible exception of fraction 6
3. Acid soil from Latekujan Farm	No marked variation ignoring fraction 2 which gives a low value	No marked or regular variation; fraction 4 gives a somewhat high value	No marked or regular variation	Increases ignoring the b. e. c. of fraction 2 at the second inflexion point	No marked variation : T_2/T_1* is nearly ignoring fraction 2 which gives the ratio 4
4. Acid soil from Oatting Farm	Decreases	Increases up to fraction 3; then decreases	Increases	Increases	No marked variation
5. Calcareous soil from Krishnagar	No appreciable variation ignoring fraction 1	Variations not marked or regular	Variations not marked or regular	Rapidly increases	No marked variation

* T_2 and T_1 are respectively the b. e. c. at the second and first inflexion points

The variations of the chemical composition and the b. e. c. of the different sub-fractions from the same soil admit of the following explanations :—

(*a*) The various fractions contain different minerals, (*b*) they contain the same mineral but different types of isomorphous replacement [Marshall, 1935] or different degrees of the same type of such replacement have occurred in the different fractions, (*c*) the various fractions contain varying proportions of 'free' silica and sesquioxides having negligible b. e. c., (*d*) the larger b. e. c.'s of the finer sub-fractions are due to their greater specific surfaces.

The marked variations in composition of the sub-fractions from the Satara, Padegaon and Oating soils may be due to any one of (*a*), (*b*) and (*c*) or any combination of them. The fact, however, that the different members of each series give the same family of titration curves rules out (*a*), and also (*b*) when the magnitude of the variations is large as considerable isomorphous replacement would be necessary to account for them and this would probably give rise to some significant variations in the form of the titration curves; (*c*) would offer a more plausible explanation in such cases; the form of the titration curves is not likely to be materially altered by the association of inert free oxides though the b. e. c. per gm. will be altered. Both (*b*) and (*c*) may be responsible for the smaller variations in composition (and the b. e. c.).

Reference has been made (Table III) to some peculiarities of Padegaon B-6 compared with the other fractions of this series. Unpublished work of S. N. Bagchi further shows that Padegaon B-6 has optical properties,

e.g. refractive index and appearance under the petrographic microscope, different from the other fractions. The electrochemical, analytical and optical evidences indicate that the mineral constituent of this fraction is different from that of the others. The entire clay fraction of the Padegaon soil has been found to give a dehydration curve similar to that of montmorillonitic clay minerals. The dehydration curves of the sub-fractions have not been separately determined.* Judging from the similarity in the form of the titration curves of fractions 1-5, the fact that their chemical composition is not constant and is also different from that of montmorillonite may be explained as mainly arising out of an isomorphous replacement of the gibbsitic Al by Fe in the lattice [Marshall, 1935]. The percentage of Al_2O_3 in Padegaon B-6 is significantly higher and its SiO_2/Al_2O_3 ratio lower than those of the other fractions. These differences, considered in the light of the somewhat different nature of its titration curve and different optical properties, indicate that Padegaon B-6 contains a different mineral, perhaps beidellite formed by the replacement of Si of the Si-O-Si layer by Al.

The fact that the sub-fractions from the Latekujan soil have nearly the same chemical composition and give similar titration curves shows that they have a uniform mineralogical make-up, the minor variations in composition being due to (*b*) and/or (*c*) mentioned above. Similar remarks apply to the sub-fractions from the Krishnagar soil. The dehydration curve of the entire clay fraction from the Latekujan soil has been found to resemble that of kaolinitic minerals, which shows that kaolinite or some other member of the kaolinite group is the dominant mineral constituent of this clay fraction. The dehydration curves of the sub-fractions have not been separately determined. The entire clay fraction, however, gives similar titration curves as the sub-fractions. All the curves reveal a weak dibasic acid character. Very significant in this connection is the unpublished observation of one of us (R. P. Mitra) that kaolinite also behaves as a weak dibasic acid† and the ratio of the base-exchange capacities at the second and first inflexion points in the titration curve of kaolinite is 2 as observed with the different sub-fractions from the Latekujan soil (except fraction 2). These evidences strongly suggest that kaolinite is the dominant mineral constituent of the different fractions (with the possible exception of fraction 2) of the Latekujan soil.

As indicated above, the differences in the b. e. c.'s of the various fractions may be also due to their having different particle sizes, and hence specific surfaces. Where the chemical composition does not show material differences as in the case of the Latekujan and Krishnagar series, the variations of the specific surface are probably mainly responsible for the changes in b. e. c. The finer the fraction the greater the surface and the larger will be the b. e. c., assuming that the interaction with the base is confined to the surface alone. The part played by the specific surface has been closely examined in the case of the sub-fractions from the Latekujan soil. The specific surface has been

* The dehydration, X-ray and optical studies of these and other sub-fractions and entire clay fractions have been undertaken and will be reported later

† The sample of kaolinite used had the composition SiO_2, 53·9 per cent, Al_2O_3, 45·5 per cent and Fe_2O_3, 0·5 per cent. The entire clay fraction separated from a 2 per cent suspension of the air-dried sample was repeatedly leached with dilute HCl to remove all exchangeable bases and then titrated with bases

obtained in three ways. S_1 has been calculated from the known equivalent spherical diameters ; S_2, from the amount of methylene blue adsorbed per gm ; and S_3 from the base-exchange capacity, assuming that the exchangeable cations are held against a monoionic layer of OH ions.* The specific surfaces and the base-exchange capacities per gm. and per sq. metre of the surface are shown in Table IV.

Table IV

Specific surfaces and the b. e. c. per gm. and per sq. metre of the surface

Reference No. of sub-fraction	Equivalent spherical diameter in microns	Sp. surface in sq. m. $\times 10^2$			Base-exchange capacity in m. e. NaOH					
					Per gm.		Per sq. m. of surface $\times 10^2$			
		S_1	S_2	S_3	T_1	T_2	T_1/S_1	T_1/S_2	T_2/S_1	T_2/S_2
1	1·06	2·2	68·5	7·5	0·09	0·20	4·10	0·13	9·1	0·29
2	0·10	23·5	107·0	14·6	0·10	0·39	2·40	0·09	1·7	0·36
3	0·07	33·5	131·0	11·6	0·165	0·31	0·50	0·13	0·9	0·24
4	0·048	49·0	131·0	12·7	0·17	0·34	0·55	0·13	0·7	0·25
5	<0·033	>62·0	131·0	13·4	0·18	0·38	<0·23	0·13	>0·5	0·27

The values of the specific surface are in the order $S_2 > S_1 > S_3$ excepting fraction 1 for which S_1 is smaller than S_3. Since the particles are generally not spherical [Marshall, 1930], S_1 should be smaller than the actual value. Besides it does not include the inner surfaces ; S_2 has consistently the largest value. Both S_2 and S_3 will include inner surfaces which appear to be considerable in magnitude. The wide discrepancy between S_2 and S_3 should, in part, be attributed to the difference in the cross-sectional areas of the methylene blue cation and OH ion. The ratio of S_2 to S_3 is nearly 10 in all the cases. In calculating S_3 the closest packing of the OH ions on the surface has been assumed. The fact that S_1 is greater than S_3 except for the coarsest fraction shows that the reactive anions, if OH, are sparsely distributed on the surface, or alternatively, the reactive anion of which OH is a component has a much larger cross-sectional area.

While T_1 and T_2 tend to increase with diminishing particle size both T_1/S_1 and T_2/S_1 increase as the particle size increases. T_1/S_2 and T_2/S_2, however, both remain practically constant excepting fraction 2. The more or less uniform chemical composition of the different fractions, the similar features of their titration curves and the practically constant value of T_1/S_2 and T_2/S_2 all point to the presence of the same reactive acid material in fractions 1, 3, 4 and 5. Considered in this light, the increase in either T_1/S_1 or T_2/S_1 with increasing particle size connotes that the particles have considerable inner surfaces and or fresh layers are progressively exposed as the reaction with the base proceeds.

* This assumption is not inconsistent with our present knowledge of the crystalline structure of clay minerals.

Summary

The chemical compositions, nature of titration curves with bases and the base-exchange capacities (b. e. c.) calculated from these curves of sub-fractions of hydrogen clay having particle sizes within specified limits and prepared by the graded centrifugalization of the entire clay fraction of two black cotton, one yellow calcareous and two acid soils have been studied.

The chemical composition of the sub-fractions obtained from either of the two black soils as also from one of the acid soils markedly changes with the particle size. No definite or regular variations are, however, observed in the case of the sub-fractions from the other acid soil or the yellow calcareous soil.

The b. e. c. per gm. (T) of the oven-dried sub-fractions separated from the same soil usually increases with diminishing particle size. When the chemical composition of any one fraction steps out of an otherwise regular variation with the particle size, its b. e. c. also shows a departure from a regular increase with diminishing particle size.

The specific surface, S_2, of each of five sub-fractions from one of the acid soils calculated from the amount of methylene blue absorbed per gm. is greater than the external surface per gm., S_1, calculated from the known particle size. The b. e. c. per sq. cm. of S_1, i.e. T/S_1, increases with increasing particle size. T/S_2, however, remains fairly constant.

The various fractions prepared from the same soil usually show the same type of titration curves. Differences have also been observed and in such cases the chemical composition and the b. e. c. are also markedly different from the other fractions.

References

Marshall, C. E. (1930). *Trans. Faraday Soc.* **26**, 173

——— (1935). *Zeit. Kristallog.* **91**, 433

Mattson, S. (1931). *Soil Sci.* **31**, 313

Mitra, R. P. (1940). *Indian J. agric. Sci.* **10**, 315

Mitra, R. P. and Chakravorty, S. K. (1939). *Proc. Indian Sci. Cong.* *3*, 184

Mukherjee, J. N., Mitra, R. P. and Chakravorty, S. K. (1942). *Indian J. agric. Sci.* **12**, 231

Whitt, S. M. and Baver, L. D. (1937). *J. Amer. Soc. Agron.* **29**, 917

A PRELIMINARY STUDY OF THE ASCENT OF WATER THROUGH SOIL COLUMNS RESTING ON A WATER TABLE, LOSS OF WATER BY EVAPORATION AND ASSOCIATED MOVEMENT OF SALTS IN THE SOIL

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(With three text-figures)

It is well known that when a soil column is resting on a water-table with the top surface exposed to the atmosphere, water will ascend through the soil column. The height up to which water will rise will depend upon the textural properties of the soil. The rate of ascent will also be influenced by the rate of removal of moisture from the surface by evaporation after the capillary connection between the soil surface and the water-table has been established. The fact that the actual rise of water is much smaller than that expected on the classical 'capillary theory' has been pointed out by several workers, *e.g.* Keen [1931], Russell [1932], Puri [1939] and others. Puri has, however, pointed out that, when calculating the maximum capillary pull, if the 'mean diameter instead of' the smallest diameter is considered, the computed values of capillary height are more in accordance with the actual rise of water.

If the top of a soil column resting above a water-table is freely exposed to the atmosphere evaporation takes place; the rate of evaporation will depend partly upon the saturation deficit and the velocity of the wind in the air layers immediately above the exposed surface and partly on the rate of arrival of moisture at the surface. During the clear season of 1939, experiments were conducted at the Central Agricultural Meteorological Observatory, Poona, to study the ascent of moisture in soil columns resting on a water-table and the loss by evaporation. A short note by Ramdas and Mallik [1939], summarizing the results obtained during the months January to March 1939, was published elsewhere. In the present paper the data recorded during the six months January to June 1939 are discussed. The upward movement of the dissolved salts in the soil column associated with the movement of water is also considered.

Materials and methods

A simple evaporimeter with bottom feed was constructed locally and used in the study of (*a*) the ascent of moisture in a soil column resting on a water-table and (*b*) the loss by evaporation from the surface. The instrument consists of a metallic cylinder 5 in. in diameter (equal to that of a standard rain gauge) containing soil and kept with its perforated bottom in contact with water in a close-fitting reservoir. Fig. 1 shows a vertical section of the evaporimeter. A series of these evaporimeters in triplicate with soil

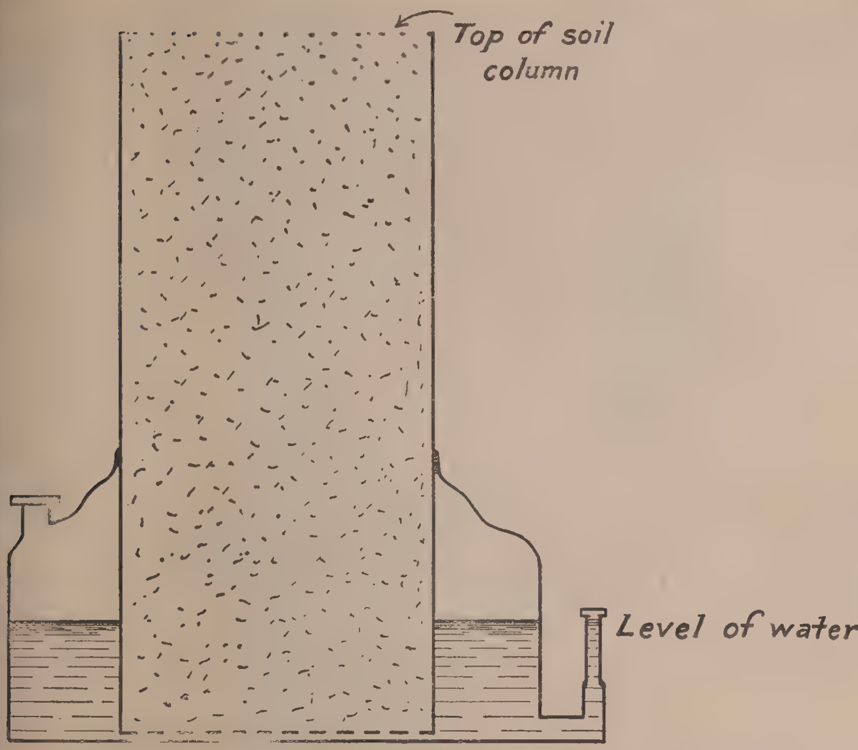

Fig. 1. Sketch of soil evaporimeter

columns 6 in., 1 ft., 1½ ft. 2 ft. and 3 ft. (15 instruments in all) were used for this study. The three instruments corresponding to each of the five depths mentioned above were filled with Poona (black cotton) soil, normal Punjab (alluvial) soil and *bari* (alkali) soil from the Punjab respectively. The black cotton soil of Poona is characterized by the black colour, a large clay fraction and a comparatively high calcium content. The alluvial soils of the Punjab are typical Indo-Gangetic valley deep soils. They are comparatively poor in clay fraction and calcium content. The essential difference between the normal and the *bari* soils is that the latter has a much larger proportion of soluble salts, thus making it poor from the agricultural point of view. Special care was taken to see that the packing of the soil into the vertical cylinders of the evaporimeters was uniform in all the instruments, the weight per in. of the soil column being same for each soil. The evaporimeters were weighed daily at 8 A.M., replenished with water up to a reference mark on a side tube of glass and weighed again. The difference between the weight after adding water on one day and the weight before adding water on the next day is the actual loss of water by evaporation from the soil surface. The evaporation is then expressed in inches by using a conversion factor. To obtain uniformity of exposure the series of soil evaporimeters were set up on suitable wooden platforms so that the tops of all the instruments were at the same level (3 ft.) above ground. The time taken by water

to rise up to the top of the soil columns (the appearance of a wet patch) of different heights in the different types of soil was noted. The daily loss of water by evaporation from each of the 15 instruments was recorded for a period of six months, January to June 1939.

To study the movement of dissolved salts associated with the upward movement of water, the *bari* soil, which has the maximum salt content, was used. The nature and percentage of the salts in the *bari* soil, obtained through the kindness of the Agricultural Chemist to the Government of Bombay, are as follows :—

Salts	Per cent
Total soluble solids	1·033
Sodium sulphate	0·750
Sodium chloride	0·218
Sodium carbonate	0·011
Sodium bicarbonate	0·014
Calcium carbonate	0·015
Magnesium carbonate	0·003

The 'total soluble solids' in the *bari* (alkali) soil was determined before packing into evaporimeters. After the experiment had run for six months, samples of the soil in the 36 in. evaporimeter were taken from depths at intervals of 3 in., beginning from the surface and ending with 36 in. These samples were then analysed for total soluble solids as indicated below. 100 gm. of the oven dry soil was shaken with distilled water in a graduated shaker and allowed to stand for 24 hours. An aliquot part of this mixture was centrifuged till an extract, clear for all practical purposes, was obtained which was then evaporated to dryness and the residue obtained weighed.

Statement and discussion of the results

Ascent of moisture in the soil columns

The evaporimeters were filled with soil, and water was added in their reservoirs ; the instruments were then exposed to the atmosphere. The time taken by water to rise to the top surface of the soil columns as indicated by the appearance of wetness and also as verified from the daily evaporation losses, was noted. Table I gives the time taken by water to rise up to different heights in the three soils investigated.

TABLE I

Time of ascent of water

Type of soil	Time taken by water to ascend to a height of				
	6 in.	1 ft.	1½ ft.	2 ft.	3 ft.
Poona soil	1 day	2 days	6 days	15 days	Surface not perfectly wet even in six months
Punjab soil (normal)	1½ days	3 days	5 days	10 days	21 days
Bari (alkali) soil from the Punjab	3 days	Surface not wetted with water even after six months			

It will be seen from Table I that, up to a thickness of 1 ft. of soil layer the upward movement of water is fastest in the black cotton soil of Poona. In the case of thicker layers, however, the time taken by water to move up in the alluvial soil of the Punjab is less than in the Poona soil. The rise of water in the *bari* (alkali) soil of the Punjab is very slow, the time taken for an upward movement of 6 in., being three times as much as in the case of the Poona soil.

Table I also shows that the height of soil column that can be wetted with water varies in the different types of soil. In the case of Poona soil, wetting of the soil surface did not occur in the 3 ft. soil column even after six months, although this happened in the Punjab alluvial soil of same depth in 21 days. This may partly be due to the greater porosity of the alluvial soil. In the *bari* (alkali) soil, the soil surface was not wetted when the water-table was more than 6 in. below the surface.

Table II gives the moisture percentages at different depths of the 3 ft. high soil column in the three types of soil at the end of the experiment, i.e. after the soil column had stood on the water-table for six months. It is seen that although the surface did not appear wet in the Poona and the *bari* soils there had actually been an increase of moisture at the surface. This is shown by the increase in the moisture per cent of the surface soil from 0·87 per cent in the beginning to 11·53 per cent at the end of the experiment in the case of the *bari* soil and 3·15-26·81 per cent in the Poona soil.

TABLE II

Moisture per cent on oven-dry basis

Depth (in.)	Poona	Punjab (normal)	Punjab (*bari*)
Surface	26·81	23·84	11·53
3	28·92	24·43	11·84
6	31·33	24·96	12·96
9	33·44	25·42	13·74
12	34·96	25·84	14·82
15	36·76	26·06	15·54
18	41·84	26·74	16·90
21	46·04	27·23	17·61
24	47·58	27·81	18·93
27	49·20	28·42	20·24
30	50·44	29·00	22·08
33	51·00	30·38	24·56
36	53·64	31·67	26·84
Before experiment	3·15	0·42	0·87

The experiments with five different depths of each of the three soil types were started on 5 December 1938. The data for the month of December are not being considered, as some time has to be allowed for all the soils to attain a steady state. The evaporation losses were recorded daily and the mean daily evaporation in inches during January, February, March, April,

May and June as well as the mean daily evaporation in inches from the standard U. S. A. evaporimeter are given in Table III.

TABLE III

Mean daily evaporation

Months of 1939	Types of soil	Mean daily evaporation in inches when the distance between the evaporating top surface of the soil column and the water-table is					Evaporation from U. S. A. evaporimeter in inches
		6 in.	1 ft.	1½ ft.	2 ft.	3 ft.	
January .	Poona soil . .	0·30	0·26	0·17	0·11	0·01	0·25
	Punjab soil (normal)	0·29	0·23	0·21	0·18	0·09	
	Bari soil from the Punjab (alkali)	0·05	0·02	0·02	0·01	0·01	
February .	Poona soil . .	0·38	0·34	0·22	0·15	0·02	0·35
	Punjab soil (normal)	0·37	0·26	0·22	0·18	0·09	
	Bari soil from the Punjab (alkali)	0·06	0·02	0·02	0·02	0·01	
March .	Poona soil . .	0·48	0·41	0·23	0·16	0·02	0·43
	Punjab soil (normal)	0·43	0·30	0·21	0·17	0·08	
	Bari soil from the Punjab (alkali)	0·05	0·03	0·03	0·02	0·01	
April .	Poona soil . .	0·48	0·40	0·23	0·16	0·01	0·48
	Punjab soil (normal)	0·51	0·31	0·23	0·18	0·09	
	Bari soil from the Punjab (alkali)	0·05	0·03	0·03	0·02	0·01	
May .	Poona soil . .	0·49	0·39	0·21	0·14	0·03	0·57
	Punjab soil (normal)	0·51	0·32	0·24	0·18	0·08	
	Bari soil from the Punjab (alkali)	0·04	0·03	0·03	0·02	0·01	
June .	Poona soil . .	0·22	0·09	0·08	0·07	0·02	0·34
	Punjab soil (normal)	0·22	0·16	0·13	0·12	0·07	
	Bari soil from the Punjab (alkali)	0·03	0·03	0·02	0·02	0·01	

From Table III the following conclusions may be drawn :—

(1) In all the types of soil under study, the amount of water lost by evaporation decreases as the water-table recedes below the evaporating surface, i.e. when the water-table is 3 ft. below the surface, the loss of water is very much less than when the water-table is 6 in. below the surface. Fig. 2 shows the variation of the evaporation loss with the distance between the water-table and the top of the soil column for the month of April 1939.

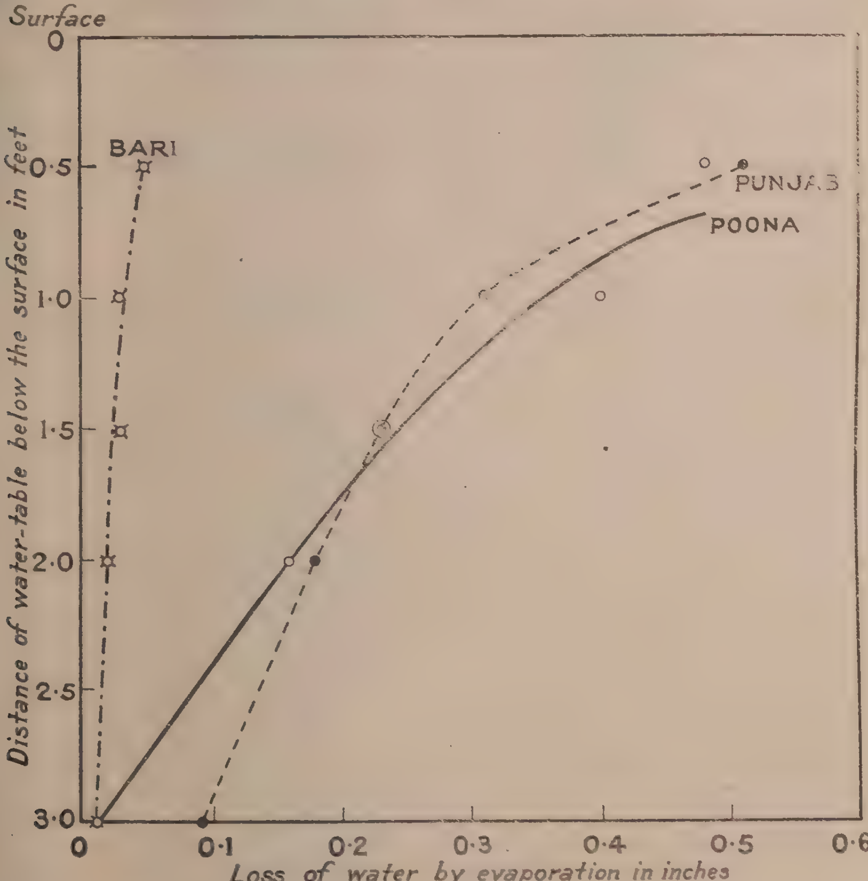

FIG. 2. Evaporation with the water-table at various depths below the surface (May 1939)

(2) Comparing the values for the three types of soil, it is seen that the loss of water from the *bari* (alkali) soil containing a large percentage of soluble salts, is very much smaller than that from either the normal Punjab soil or the black cotton soil of Poona for all the depths of the water-table considered in these experiments. It appears that the amount of water

lost from the Punjab normal soil and the Poona soil is about the same, with this difference, however, that when the water-table recedes below $1\frac{1}{2}$ ft. from the surface, evaporation from the alluvial soil of the Punjab (which is more porous) is somewhat more than from the black cotton soil of Poona (which has a larger clay fraction and is less porous).

(3) As is to be expected, evaporation increases with the advance of the season and then decreases with the advent of monsoon conditions. This is found to be true for all the three types of soil under investigation and for all the depths of the water table below the surface as well as for the evaporation recorded in the U. S. A. evaporimeter. April and May are the months of high evaporation.

Vertical movement of the dissolved salts

The distribution of the soluble salts in the *bari* (alkali) soil column resting on water (*i*) at the commencement and (*ii*) after the experiment had run for six months is given in Table IV. These values refer to the soil in the 3 ft. deep instrument.

TABLE IV

Total soluble solids in the bari *(alkali) soil from the Punjab expressed as per cent on oven-dry basis*

Distance below the evaporating surface (in.)	Before the experiment	After the experiment
Surface	1·11 Uniform throughout the soil column	4·65
3		3·22
6		2·20
9		1·23
12		0·92
15		0·80
18		0·62
21		0·48
24		0·42
27		0·33
30		0·20
33		0·10
36 (Resting on water-table)		0·06

Table IV clearly reveals that there has been an upward movement of the salts in the soil. As the water moves up through the soil column it dissolves some of the soluble salts during its passage and reaches the top evaporating surface as a concentrated salt solution. There the water evaporates leaving the salts at the top layer. This process goes on so long as water is moving up and evaporating from the top. Thus, after some time, the salt content at the top becomes considerably higher than in the lower layers.

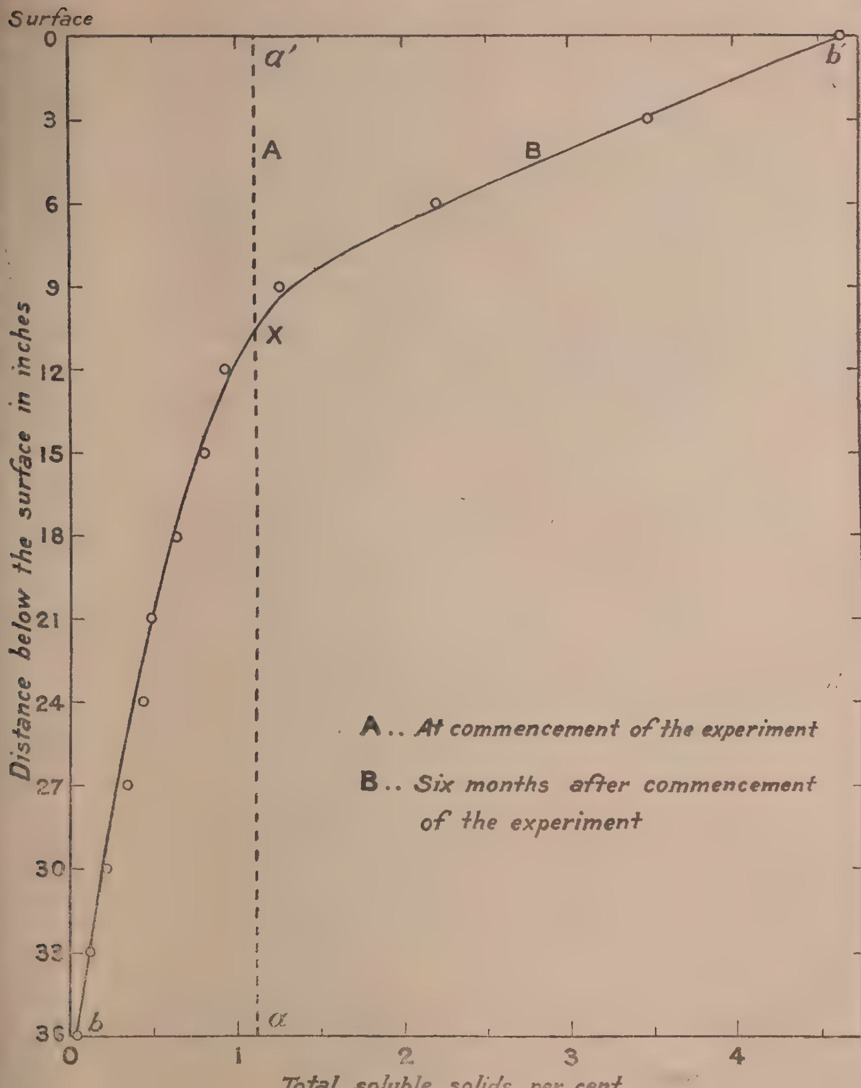

FIG. 3. Movement of the salts in the *Bari* soil from the Punjab

Fig. 3 shows the distribution of salts before and after the experiment in the case of the *bari* (alkali) soil. Although the distribution of the salt is altered, the total amount of salt in the apparatus has remained sensibly unaltered as is shown by the equality in the areas enclosed between the lines A and B in triangles a × b and a′ × b′. It may be pointed out here that, as seen from Table II, water did rise to the surface through a 3 ft. soil column even in the case of the *bari* soil although the surface did not appear wet.

It may be recalled that one of the methods for the reclamation of alkali soil is by irrigating the fields and allowing the water to evaporate and finally, after some time, removing surface layers from the fields by scraping.

Further investigations on the salt content in relation to movement of water through soils are in progress.

My best thanks are due to Dr L. A. Ramdas, Agricultural Meteorologist, for suggesting the problem and guidance during the course of the work and to the Director of Agriculture of the Punjab for kindly arranging for the supply of the Punjab soils used in this investigation.

REFERENCES

Keen, B.A. (1931). *The Physical Properties of the Soil*. Longmans, Green & Co.
Puri, A. N. (1939). *Soil Sci.* **48**
Ramdas, L. A. and Mallik, A. K. (1939). *Curr. Sci.* **8**, 6
Russell, E. J. (1932). *Soil Conditions and Plant Growth*. Longmans, Green & Co.

REVIEW

An Agricultural Testament. By SIR ALBERT HOWARD (Oxford University Press, Bombay, 1940, pp. 253, 15s.)

THE title of the book is so alluring that any one interested in agriculture will be tempted to add this book to his library. As a literary work also, it forms fascinating reading. On Biblical analogy one, however, expects ten commandments ; but Sir Albert has only one commandment, viz., compost—nay compost prepared by his Indore Method only. There should not be the slightest contamination of artificials even as starter for decomposition as recommended by the Adco process. According to the author, one must not touch artificials even with a pitch fork if soil fertility is to be maintained. This 'back to nature' protest from a westerner is really refreshing.

As a counterblast to Liebig's theory of mineral nutrition, this book might have rendered valuable service at the time. Liebig belittled the existing theory that the value of bulky manures lay in their organic matter and expounded a new one that it lay in their ash constituents. This marked the beginning of the mineral theory of nutrition and as a result, a school of scientists arose which asserted that artificial manures were not only more remunerative than dung but were the only way of keeping up soil fertility and the practice of adding bulky manures was not an essential feature of agriculture. The advent of bacteriology and the development of soil physics, however, falsified this view by showing that soil fertility is not a simple chemical problem as propounded by the mineral school of thought. Research has thus definitely established the importance of organic matter in crop production and the need for the maintenance of its supply is now acknowledged in any modern method of husbandry, while in forests the removal of leaves and other decomposable matter is recognized as undesirable. Artificials are not condemned, but it has been recognized that the full benefit of artificials can be realized only when the supply of humus has been adequately provided for. There is thus a great field for artificials when this condition is satisfied.

The book would have been thus passed over by us as one more addition to the existing literature on humus, if the author had not downright condemned artificials, making at the same time extravagant claims for composts (prepared by his method only), which could not be substantiated by existing facts. Some of the generalizations made by him are also dangerous as they are partly true. Taking only one instance, the author maintains that a plant grown in soil treated with compost without any artificial manuring will be practically free from pests and diseases and therefore the present organization of entomological and mycological research is a gigantic and expensive failure. It is quite true that depredations of certain insects can be greatly reduced by securing a vigorous plant. There are, however, a great number of insects which are observed to thrive in proportion to the vigour of the host plant. Pyrilla, white fly and rice grass hopper are some of the common instances. As regards artificials, Russell, in his recent review of the famous Broadbalk wheat experiment at the Rothamsted Experimental Station (Technical Communication

No. 40) found no special effect of artificial fertilizers on the incidence of insect-attack even after 88 years of continuous manuring. It seems not to have been realized by Sir Albert that climate exerts a great influence on the spread of insect pests and diseases and it would be thus risky to generalize from a few casual observations. At the same time, it cannot be denied that in the case of artificial fertilizers there is a risk of increased susceptibility to diseases owing to unbalanced nutrition. For instance, a heavy dose of sulphate of ammonia or nitrate of soda will lead to the development of crinkled soft sappy leaves liable to insect and fungus pests in case of potassic deficiency. The use of artificials alone may also create deficiency of some of the minor elements as boron, manganese, etc. which are known to have stimulative and prophylactic effects. A good scientific background is, therefore, essential for the proper use of artificial fertilizers in a balanced nutrition and all the ills attributed to them by the author are due to his lack of appreciation of this fact.

The book bristles with similar statements which it would not be possible to place in proper perspective in a short review. As a rule, these statements are based on general observations and, time and again, the author has made it quite clear that he does not believe in quantitative data as obtained at experimental stations and has pooh-poohed the use of statistics in the interpretation of the same. Further, although the author has used four chapters, occupying about one-third of the book, in discussing the development of the Indore process, there is no mention, throughout, of the economics of the method. Like statistics, economics are also anathema to him. These shortcomings, greatly detract from the value of the book as a scientific monograph.

This obsession of the author about the celestial qualities of compost is also the keynote of his condemnation of the organization of present-day agricultural research. The problem is not, however, so simple that all agricultural ills can be cured by soil aeration and by regular supplies of freshly prepared humus from animal and vegetable wastes. These remedies of the author cannot also supply the rising needs of the human as well as of industrial hunger and in this connection there should be no denying the fact that artificial fertilizers have a future.

Agriculture embraces many associated sciences and considering the rapid progress which these sciences have made during the last decade, in any organization of agricultural research it is but rational to imagine that one researcher cannot tackle the problem in all its aspects and that team work is the only solution. This, however, necessitates the fragmentation of the problem and the establishment of research institutes—only on the basis of the particular science militates against that high standard of professional cooperation which is required for successful team work. The tendency of the workers in these institutes would be to confine themselves to some aspects of their specialized field. To take only one instance, the breeding institutes confine themselves, to breeding either high yielding or disease-resistant varieties. When such a a variety is released in general cultivation, nothing is known of its nutrition and this is the reason why deterioration of varieties after a few years' trial is reported so often. In fact, hardly a single breeding institute possesses a

Physiologist to carry out these important studies on which the future of the variety depends. The author is, therefore, as usual, partly right when he condemns the present tendency of excessive departmentalization and too much specialization in agricultural research.

Industry has created a new hunger of the machine for raw products. It is, therefore, no use closing our eyes to the fact that the fields will have to respond to the hungers of both the stomach and the machine. The author has, however, got no solution for this. Science connotes progress and the role of the real scientist is not to ask us to go back to nature or adopt a safe method when by following the same it would not be possible to satisfy both these hungers. A large number of experiments throughout the world has proved that humus is necessary for maintaining soil fertility and artificials are capable of giving record yields of great economic value. It is, therefore, felt that if instead of assuming the role of the Apostle of Humus by making extravagant claims for it and by condemning artificials, Sir Albert had attempted in this book to focus our attention on the possible method of bringing artificials into ' gear ' with humus, he would have certainly done a great service to the agricultural world and would have justified the title of the book.—(R. D. R.)

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